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Demonstration of Low-NO_x Burner Retrofit for Dual-Fuel Package Boilers: Equipment Selection Criteria and Initial Findings

by
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Innovative Ideas for the Operation, Maintenance, & Repair of Army Facilities

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The Department of Defense operates nearly 600 Army boilers serving small clusters separate from central heating networks. Air pollution control regulations may require that these burners be either replaced or made cleaner and more efficient. Improved performance may be possible by retrofitting these small conventional boilers with high-efficiency, low nitrogen oxide (NO_x) dual-fuel burners in the 4 to 30 million Btu per hour (MBtu/h) firing range.

In this study, low-NO_x replacement burners were retrofitted to firetube boilers at two Army installations for side-by-side comparison with conventional burners based on efficiency, cleanliness, and cost payback. Replacement burners were selected by the following minimum criteria: (1) a 5:1 turndown ratio, (2) excess air requirements of 10 to 20 percent throughout the firing range, and (3) emission levels of less than 50 ppm NO_x and carbon monoxide (CO).

Preliminary findings show that retrofit of high-efficiency burner systems to firetube boilers may result in lowered NO_x emissions and a slight average efficiency gain compared to conventional burner systems. Based on present findings, fuel savings are calculated to recover additional capital cost in less that 4 years. Long-range monitoring and performance analysis continues.

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FOREWORD

This work was performed for the U.S. Army Engineering and Housing Support Center (USAEHSC), Fort Belvoir, VA, under the Facilities Engineering Application Program (FEAP), Project FW1, "High-Efficiency, Low-NO_x, Dual-Fuel Burner System for Water Tube Boilers." The technical monitor was S. Sharma, CEHSC-FU-M.

This work was performed by the Energy and Utility Systems Division (FE), of the Infrastructure Laboratory (FL), of the U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Noel L. Potts. Dr. David M. Joncich is Chief, CECER-FE, and Dr. Michael J. O'Connor is Chief, CECER-FL. The USACERL technical editor was William J. Wolfe, Information Management Office.

COL Daniel Waldo, Jr., is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

In FY88 the U.S. Army spent $432 million on heating operations, $172 million for natural gas-fired operations, and $175 million for oil. The Army has a stated goal to reduce energy consumption during the 1985 to 1995 period by 8 percent on a Btu/sq ft-yr* basis in existing structures, and by 10 percent on a Btu/unit-produced in industrial processes.** The Army also plans to raise the productivity of its personnel (by providing energy systems that reduce adverse environmental effects), and to enhance energy security through dual fuel capability. Unfortunately, post engineering personnel often lack the time needed to investigate new ways to save energy or new operation and maintenance techniques like those offered by high-efficiency, low nitrogen oxide (NO_x) burners.

In addition to meeting energy conservation goals, low NO_x burners are also needed to meet air pollution emission limits. In 1980, stationary sources including utility and industrial boilers accounted for about 55 percent of the NO_x emissions in the United States.[1] The U.S. Environmental Protection Agency (USEPA) has established emission limits for both utility and industrial boilers.

In 1990, the Department of the Army (DA) consumed 93.6 billion Btus of energy in the United States. About 50 percent of this amount was used by boilers to provide space heating, domestic hot water, and process heat. Of the Army's 1300 boilers throughout the United States, about 90 percent burn oil or natural gas and 10 percent burn coal. Although the Army operates about 75 central heating plants (CHPs) with capacities between 30 and 300 MBtu/h, most of its boilers (about 1100) are in the 4 to 30 MBtu/h range and serve small building clusters isolated from their installations' central heating networks. These boilers are usually of firetube construction and burn No. 2 oil or natural gas. Because of their relatively small size, they are often overlooked in energy conservation programs.

Nitrogen oxides (NO_x) emission is a major contributor to air pollution in urban areas. One source of NO_x is burners on industrial size boilers that provide heating or process steam, which are responsible for over 9 percent of NO_x emissions. Unlike the CHPs, however, small boilers have typically not been required to meet stringent air pollution emission limits. USEPA regulations for boilers between 10 and 100 MBtu/h only limit opacity (20 percent) and sulfur oxides (0.5 lb/MBtu) emissions. Most states have adopted similar limits for opacity and sulfur oxides and have added limits for particulates, usually at 0.1 lb/MBtu. Some states also limit carbon monoxide (CO) emissions. Illinois limits all boilers to 200 parts per million (ppm) CO, a level consistent with safe boiler operating practices. Most small boilers can meet the USEPA and state limitations with good operating practices and fuel specifications.

The USEPA also limits NO_x for boilers over 100 MBtu/h. California's South Coast Air Quality Management District (SCAQMD), however, has passed emission regulations for NO_x emissions from small

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* A metric conversion table is provided on p 48.

**The Department of Defense (DOD) Defense Energy Program Policy Memorandum 86-3.

[1] *Nitrogen Oxide Control for Stationary Combustion Sources*, EPA/625/486/020 (U.S. Environmental Protection Agency [USEPA], 1986).

boilers. SCAQMD limits new boilers with a 20 MBtu/h and lower capacity to 30 ppm; those over 20 MBtu/h are limited to 9 ppm NO_x. Existing boilers between 2 and 5 MBtu/h are generally limited to 30 ppm; between 5 and 40 MBtu/h, to 40 ppm; and above 40 MBtu/h, to 30 ppm.

It is likely that other state emission regulations will follow California's lead, reflecting the technological ability to reduce NO_x emissions for all boiler sizes. To meet these requirements, a new generation of burners is being developed for the new and replacement burner market.

Research by the natural gas and oil industry has produced efficient and clean industrial-size, replacement dual-fuel burners. These burners have excellent turndown ratios (5:1), efficient performance requiring only 10 to 20 percent excess air throughout the entire operating range, and emissions less than 50 ppm for NO_x, CO, and unburned hydrocarbons (UHCs) while burning natural gas.

This study investigated burner replacement on small Army boilers. The retrofit of boilers with such high-efficiency, low-NO_x, dual-fuel burners is calculated to give a 40 percent rate of return on the initial investment due to a 3 to 5 percent increase in thermal efficiency and a 4 percent decrease in boiler fuel consumption. Current information shows that, for most applications, this fuel savings will recover the additional capital cost of the burner retrofit in less than 4 years. In addition, improved combustion can increase boiler capacity and reduce maintenance requirements for firetube cleaning.

Objectives

The overall objective of this demonstration was to evaluate the performance and reliability of retrofit application of high-efficiency, low-NO_x burners to firetube burners by performing a side-by-side comparison of this technology with conventional burner systems. If low-NO_x burners compared favorably to conventional systems, a further objective was also to determine operation and maintenance requirements of the retrofit systems, and to provide guidance for product application.

The objectives of this first part of the research were to (1) locate appropriate test sites, (2) identify and contact manufacturers of high-efficiency, low-NO_x burners, (3) select and acquire burners that best meet Army requirements, and (4) establish a program to install low-NO_x burners in conventional boilers and to monitor and compare the low-NO_x systems with conventional burners.

Approach

This part of the demonstration took the following steps:

1. Army installations were surveyed to find suitable sites for a demonstration of high-efficiency, low-NO_x burners.

2. The characteristics of Army boilers that could benefit most from burner replacement were identified.

3. A market survey identified available high-efficiency, low-NO_x burners that would fit Army boilers.

4. A set of criteria was developed to help select burners with the greatest potential for reducing energy consumption, reducing air pollution, and lowering operation and maintenance costs.

5. Candidate burners were purchased, installed, and demonstrated on Army boilers.

6. Data taken from the demonstration were systematically compared to similar data taken from conventional burner systems.

Long range monitoring and peformance analysis was established and is in progress.

Scope

This demonstration focuses specifically on high-efficiency, low-NO_x burners with a potential to improve the cost-effectiveness of Army dual-fuel package boilers.

Mode of Technology Transfer

It is recommended that the results of this demonstration be incorporated into Technical Manual (TM) 5-650, *Repairs and Utilities: Central Boiler Plants* (Headquarters, U.S. Army Corps of Engineers [HQUSACE], 13 October 1989), and Corps of Engineers Guide Specification (CEGS) 15561, "Central Steam Generating System, Combination Gas and Oil Fired" (HQUSACE, June 1989).

2 STRATEGY PLANNING

Researchers worked to develop standards for evaluating current market burner technology. Table 1 lists the target specifications of the desired burners and Table 2 shows the evaluation criteria. The significance of each target specification is expressed in terms of weight factors.

As part of this task, a planning conference was held to determine the best approach for selecting and field testing high-efficiency, low-NO_x burners. The following items were discussed and determined.

Burner Evaluation Criteria

The evaluation criteria (Table 2) were based on the target specifications for the high-efficiency, low-NO_x burners. The criteria were found acceptable, and were augmented with a weighting factor for each specification based on its significance.

Table 1

Target Specifications for High-Efficiency, Low-NO_x, Dual-Fuel Burners for Firetube Boilers

No.	Criteria	Measure
1	Range of nominal sizes required	4×10^6 to 32×10^6 Btu/h (in several steps)
2	Combustion chamber specific heat density	120,000 to 150,000 Btu/cu ft-h
3	Water-cooled cylindrical combustion chamber diameter (Morison tube)	22 in. at 4×10^6 to 45 in. at 30×10^6 Btu/h
4	Combustion chamber length-to-diameter ratio	From 6 to 7.5
5	NO_x, CO, and UHC emissions for natural gas and No. 2 oil (at ambient combustion air temperature)	Not more than 50 ppm each
6	Soot emissions for No. 2 oil	No. 2 Bacharach or less
7	Burner noise level	85 dba or less at 3 ft
8	Excess air requirements for natural gas firing	a) At nominal capacity, 5% or less b) At 5:1 turndown, 10% or less
	Excess air requirements for No. 2 oil firing	a) At nominal capacity, 8% or less b) At 5:1 turndown, 12% or less
9	Pressure requirements for fuel and combustion air	As low as possible
10	Burner Turndown ratio:	a) Natural gas, 5:1 b) No. 2 oil, 5:1

Table 2

Evaluation Criteria for High-Efficiency, Low-NO_x Burners for Firetube Boilers

Weight Factor	Criteria			
0.05	1. Range of Nominal Burner Size (10^6 Btu/h)			
	(4, 8, 16, 32)			
	All four	--	10 points	(TARGET)
	3 of 4	--	8 points	
	2 of 4	--	5 points	
	1 or less	--	0 points	
0.05	2. Combustion chamber Specific Heat Density (Btu/cu ft-h)			
	>145,000	--	10 points	(TARGET)
	<145,000	--	9 points	
	<140,000	-	8 points	
	<135,000	--	7 points	
	<130,000	--	6 points	
	<125,000	--	5 points	
	<120,000	--	0 points	
0.03	3. Minimum Water-Cooled Combustion Chamber Diameter (in.)			
	(at 4 X 10^6 Btu/h)			
	<22 in.	--	10 points	(TARGET)
	<23 in.	--	5 points	
	>23 in.	--	0 points	
	(at 32 X 10^6 Btu/h)			
	<45 in.	--	10 points	(TARGET)
	<47 in.	--	5 points	
	>47 in.	--	0 points	
0.02	4. Combustion Chamber L/D Ratio			
	<6	--	10 points	(TARGET)
	<7	--	8 points	
	<7.5	--	5 points	
	>7.5	--	0 points	
0.10	5. NO_x and UHC			
	<50 ppm	--	10 points	(TARGET)
	<55 ppm	--	9.5 points	
	<60 ppm	--	8.5 points	
	<65 ppm	--	7 points	
	<70 ppm	--	5 points	
	>70 ppm	--	0 points	
	CO			
	<50 ppm	--	10 points	(TARGET)
	<90 ppm	--	9.5 points	
	<130 ppm	--	8.5 points	
	<170 ppm	--	7 points	
	<210 ppm	--	5 points	
	>210 ppm	--	0 points	

Table 2 (Cont'd)

Weight Factor	Criteria
0.05	6. Soot Emissions for No. 2 Oil

<No. 1 Bach.	--	15 points	
<No. 2 Bach.	--	10 points	(TARGET)
<No. 3 Bach.	--	5 points	
>No. 3 Bach.	--	0 points	

Weight Factor	Criteria
0.08	7. Burner Noise Level (at 3 ft)

<85 dba	--	10 points	(TARGET)
<87 dba	--	5 points	
>87 dba	--	0 points	

Weight Factor	Criteria
0.30	8. Excess Air Requirements

Gas		Oil			
Nominal	At 5:1 or 4:1 Turndown	Nominal	At 5:1 or 4:1 Turndown		
< 5%	<10%	< 8%	<12%	10 points	(TARGET)
< 6%	<12%	< 9%	<14%	9 points	
< 7%	<14%	<10%	<16%	8 points	
< 8%	<16%	<11%	<18%	7 points	
< 9%	<18%	<12%	<20%	6 points	
<10%	<20%	<13%	<22%	5 points	
>10%	>20%	>13%	>22%	0 points	

Weight Factor	Criteria
0.04	9. Pressure Requirements (for 8 X 10^6 Btu/h)

Combustion Air, in. wc	Oil, psi		
< 8	<100	10 points	(TARGET)
<12	<200	9 points	
<16	<300	8 points	
<20	<300	7 points	
<24	<300	6 points	
<30	<300	5 points	
<34	>300	4 points	
<38		3 points	
<42		2 points	
<46		1 point	
>46		0 points	

Weight Factor	Criteria
0.10	10. Burner Turndown

Natural Gas	Oil		
5:1	5:1	10 points	(TARGET)
4:1	4:1	5 points	
<4:1	<4:1	0 points	

Weight Factor	Criteria
0.18	11. Estimated Life Cycle Cost

Field Test Site Selection

To minimize costs and facilitate testing of high-efficiency, low-NO_x burners, the following list of features that would be desirable in the field test boiler were prepared:

- Firetube boiler
- 175 to 300 hp
- System should be in good physical and operating condition
- System should be well sealed against air infiltration
- Boilers should represent majority of Army-operated firetube boiler designs.
- At least two similar boilers should be available at the same sites--both available for simultaneous comparison of hi-efficiency burners to conventional burners on separate boilers.
- Technical personnel with a knowledge of instruments as well as all phases of boiler operations should be available at the site.
- Boiler should be accessible, i.e., it should have: (1) enough space around the burner to allow installation of modifications; (2) at least 3 ft on each side of the boiler and at least 8 ft from the burner mounting plate.
- Stack should be accessible for instrumentation. (If stack is common to several boilers, the connecting ducts should be at least 10 duct diameters long and should be accessible.)

Field Test Measurements and Equipment

To allow comparison of boiler performance of the new, state-of-the-art burners with the conventional burners, a preliminary list of measurements and equipment was discussed and approved. Table 3 lists equipment chosen to meet the necessary efficiency and emission measurements.

Boiler efficiency can be defined as a ratio of the heat absorbed by the water for steam production to the fuel heat input. The amount of fuel heat input can be calculated from the measured fuel flow rate and the fuel heating value.

For heat output, there are essentially two available options. First, one can attempt to measure the actual boiler output (steam flow, steam temperature, and steam pressure) that could be used to calculate the amount of heat in the product steam. The presence of moisture in the steam, however, would not only complicate the steam flow measurement (necessitating indirect measurement through makeup water) but would also make it difficult to estimate the amount of heat in the steam. Further, the steam and hot water losses during boiler blowdowns would have to be accounted for. This approach to efficiency measurement, therefore, may not be practical because of the large number of boilers involved considering the scope of the current program.

The second approach estimates boiler efficiency by measuring the stack gas losses. The stack gas losses are calculated from temperature and excess O_2 measurements. This method assumes that all heat not lost through the stack goes to produce steam. It does not account for surface heat losses, which are generally low (2 percent).

The second approach was selected as the more practical for the current program, especially since the boilers compared were similar and could be expected to have similar surface heat losses. A similar method is also used by boiler operators for routine efficiency monitoring.

Table 3

Estimated Analytical Equipment Requirements per Boiler

Fuel Flow			
Natural Gas	**No. 2 Oil**	**Steam Flow**	**Flue Gas Analyzer**
Flow meter	Flow meter	Flow meter	O_2 analyzer
Pressure transducer	Indicator/ processor	Pressure transducer	CO analyzer
Thermocouple		Thermocouple	UHC analyzer
Indicator/processor		Indicator/processor	NO_x analyzer
			Opacity meter
			Thermocouple/ indicator

3 BURNER SURVEY AND EVALUATION

At the start of the program, a list of burner manufacturers that could potentially supply advanced burners for firetube boilers was compiled. The list (Appendix A) is believed to represent a majority of burner manufacturers in the United States as well as in Europe and in Japan.

A letter of inquiry (Appendix B), seeking a dual-fuel, high-efficiency, low-NO_x burner for firetube boilers, was drafted and sent to all the manufacturers together with the desired target specifications (Table 1) and a questionnaire. The questionnaire (Figure 1) was prepared to elicit more detailed manufacturer responses, and to facilitate evaluation of the burner technology.

Table 4 shows the survey results. Companies that did not respond initially were contacted by phone and followed up by a second set of forms, if necessary. A total of 104 manufacturers were contacted during the survey; 18 replied positively, indicating they had a burner they believed met our requirements. Of these, six manufacturers were European, and the remaining were domestic. Thirty-five companies replied negatively. The remaining 51 manufacturers either did not reply or could not be located.

The evaluation criteria (Table 2) developed during the program were used to screen the candidate burners. Burner specifications provided by the manufacturers were used to determine points gained for each of the 10 specifications listed in the letter. These points were then multiplied by the respective weighting factors, and the results were totaled to score each burner.

Appendix C includes the details of the points received by each burner. Table 5 lists the overall burner scores. The top eight burners were selected for further analysis. Following is a brief description of each of these burners presented in order of overall score.

Dunphy Oil and Gas Burners, Ltd.

Dunphy offered their TD Series Burner, shown in Figure 2, which either met or exceeded all the target specifications. The burner uses axial air flow distribution based on a turbine principle that is claimed to provide control over the radial swirl and axial velocity, thereby resulting in maximum combustion efficiency and accurate flame shaping. In addition, while the burner operates on gas, a two-stage device is said to eliminate low frequency resonance and allows extremely low excess air operation requiring low air pressure.

The forced draft (FD) fan motor is mounted within the air stream. This eliminates the requirements for a motor cooling fan, and also recovers the heat into combustion air. These burners are also equipped with a patented UNIBLOC™ Unified Gas Train, which is said to be a unique multifunctional gas valve that combines twin safety shutoff valves, two-stage control valves, a gas filter, and manual ball valves in a compact package.

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: ______________________________

Burner Model: ______________________________

Burner Status: Existing Under Development (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different. Please indicate units if different from those listed.

1. Range of nominal burner size (Btu/h): ____________

2. Combustion chamber specific heat density at nominal capacity (Btu/cu ft-h): ____________

3. Minimum required water-cooled combustion chamber diameter (in.)
   - at 4×10^6 Btu/h: ____________
   - at 8×10^6 Btu/h: ____________
   - at 32×10^6 Btu/h: ____________

4. Combustion chamber length-to-diameter ratio
   - at 4×10^6 Btu/h: ____________
   - at 8×10^6 Btu/h: ____________
   - at 32×10^6 Btu/h: ____________

5. NO_x, CO, and UHC emissions with ambient combustion air for:

	NO_x (ppm)	CO (ppm)	UHC (ppm)
a. Natural gas			
at nominal capacity:	____	____	____
at ___:1 turndown:	____	____	____
b. No. 2 oil			
at nominal capacity:	____	____	____
at ___:1 turndown:	____	____	____

6. Soot emissions for No 2 oil (Bacharach No.): ____________

7. Burner noise level (dba at 3 ft): ____________

8. Excess air requirements
   a. For natural gas firing
      - at nominal capacity (%): ____________
      - at 5:1 turndown (%): ____________
   b. For No. 2 oil firing
      - at nominal capacity (5%): ____________
      - at 5:1 turndown (%): ____________

9. Required pressures
   a. Air (in. wc): ____________
   b. Natural gas (in. wc): ____________
   c. No. 2 oil (lb/sq in.): ____________

10. Turndown ratio (burner output)
    a. Natural gas: ____________
    b. No. 2 oil: ____________

11. Oil atomizing fluid
    - Type: ____________
    - Flow (lb/lb oil): ____________
    - Pressure (psig): ____________

Figure 1. Inquiry-Letter Questionnaire.

Table 4

Burner Survey Results

Manufacturer	Positive Reply	Negative Reply	Did Not Reply	Returned
A.A. Engelhardt, Inc.		x		
Ace Engineering Co.		x		
Acurex		x		
Aerogen Company, Ltd.			x	
Alzeta		x		
Babcock & Wilcox Co.		x		
Baker Perkins, Inc.		x		
Barber Mfg. Co., Inc.		x		
Bard Manufacturing Co.		x		
BDP Company			x	
Beltran Associates		x		
Benraad BV			x	
Bertin and Cie			x	
Bloom Engineering Co., Inc.	x			
The British Combustion Equipment Mfrs. Assn. (forwarded to members)			x	
Burdett Mfg. Co.		x		
Caloric Gesellschaft fur Apparatebau m.b.H.			x	
Cleaver Brooks Div. of Aqua-Chem, Inc.		x		
Clyde Fuel Systems, Ltd.			x	
C.M. Kemp Mfg. Co.		x		
Coen Company, Inc.	x			
Combustion Engineering, Inc.		x		
Coppus Engineering Corp.		x		
Dr. Schmitz + Apelt Industrieofenbau GmbH	x			
DRU			x	
Dunham Busch, Inc.		x		
Dunphy Oil & Gas Burners, Ltd.	x			
Eclipse Combustion Div. of Eclipse, Inc.		x		
Eisenwerk Theodor Loos GmbH			x	
The Engineer Co.	x			
Flameco BV			x	
Forney Engineering Co.	x			
Foster Wheeler		x		
Fuel Efficiency Inc.				x
Furigas			x	
General Combustion Co.		x		
Gordon-Piatt Energy Group, Inc.	x			
Hague International	x			
Hamworthy Engrg., Ltd. Combustion Division	x			
Hauck Mfg. Co.	x			
Hirt Combustion Engineers	x			
Hitachi Zosen			x	
Hovin BV			x	
H. Saacke Eurotherms, Ltd.			x	
Iron-Fireman (same as Dunham Busch)		x		
Ishikawajima-Harima Heavy Ind.			x	
JHW of America, Inc.			x	

Table 4 (Cont'd)

Manufacturer	Positive Reply	Negative Reply	Did Not Reply	Returned
Johnston Manufacturing Co.		×		
John Zink Co.	×			
Kawasaki Heavy Industries			×	
Keeler-Dorr Oliver Co.			×	
Kobe Steel, Ltd.			×	
Kromschroder, AG			×	
Laidlaw Drew & Co., Ltd.		×		
Leahy Manufacturing Co.			×	
Max Weishaupt GmbH	×			
Maxon Corp.		×		
Mid-Continental Metal Products		×		
Midland-Ross Corp.			×	
Mitsubishi Heavy Ind., Ltd.			×	
NAO, Inc.	×			
Nebraska Boiler Co.		×		
Nippon Furnace Kogyo Kaisha Ltd.			×	
North American Mfg. Co.			×	
Nu-Way Eclipse, Ltd.			×	
Nu-Way Heating Plants, Ltd.			×	
Oertli, c/o Tobler Bros.				×
Osaka Gas Co., Ltd.			×	
Peabody Engineering (same as Gordon-Piatt)		×		
Perfection Constructors Co.				×
Pillard Inc.	×			
Process Combustion Corp.				×
Puripher			×	
Pyronics, Inc.		×		
Radiant Superjet, Ltd.			×	
Ransom Gas Industries, Inc.				×
Ray Burner Co.		×		
Riello O.F.R. (Ossicine Frateooi Riello)		×		
Riley Stoker				×
Riley Stoker		×		
Roberts-Gordon Appl. Corp.		×		
Selas Corp. of America		×		
Smit Ovens BV	×			
S.P. Kinney Engrs., Inc.		×		
The Stacey Mfg. Co.		×		
Steinmuller GmbH		×		
S.T. Johnson Co.			×	
Stordy			×	
Stordy Combustions Engrg., Ltd.			×	
Sunbeam Equipment Corp.			×	
Superior Combustion Ind.			×	
Syncro-Flame Inc.				×
Tate Jones			×	
T.C. Williams Burners Holme Mfg. Co., Ltd.			×	
Thermal Systems Engrg., Inc.			×	
Tokyo Gas Co., Ltd.			×	
Trane Thermal Co.			×	
TRW			×	
UE Corp.	×			
Voorheis Industries, Inc.	×			

Table 4 (Cont'd)

Manufacturer	Positive Reply	Negative Reply	Did Not Reply	Returned
Walter H. Edwards Engrg. Corp.				×
Webster Engrg. Div.			×	
Whites Burners			×	
Wingaersheek, Inc.		×		
W.N. Best Combustion Equip. Co.			×	
Totals (104)	18	33	45	8

Table 5

Overall Burner Score

Manufacturer	Overall Point Score
Dunphy Oil & Gas Burners, Ltd.	820
Voorheis Industries, Inc.	818
Hague International	816
Smit Ovens BV	788
UE Corporation	787
Hirt Combustion Engineers	784
The Engineer Company	783
John Zink Company	760
Hauck Manufacturing Company	660
Coen Company, Inc.	639
Gordon-Piatt Energy Group, Inc.	578
Pillard, Inc.	569
Bloom Engineering Co., Inc.	553
Max Weishaupt GmbH	487
Hamworthy Engineering, Ltd.	483
Dr. Schmitz & Apelt	427
Forney Engineering Company	410
NAO, Inc.	346

Voorheis Industries, Inc.

The Bluff-Body™ Register Burner (Figure 3) uses multiple rows of Bluff-Body elements to generate turbulence and mixing. The burner is said to feature exceptional combustion air balance while eliminating rotational spin and providing flame stability and nondivergent flame over a wide turndown ratio. The nondivergent flame is said to minimize CO and hydrocarbon emissions by avoiding impingement and, combined with multiple stages of air inlet, greatly minimizing NO_x formation. The combustion air pressure requirements are very low, and with natural gas, turndown is claimed to be unlimited.

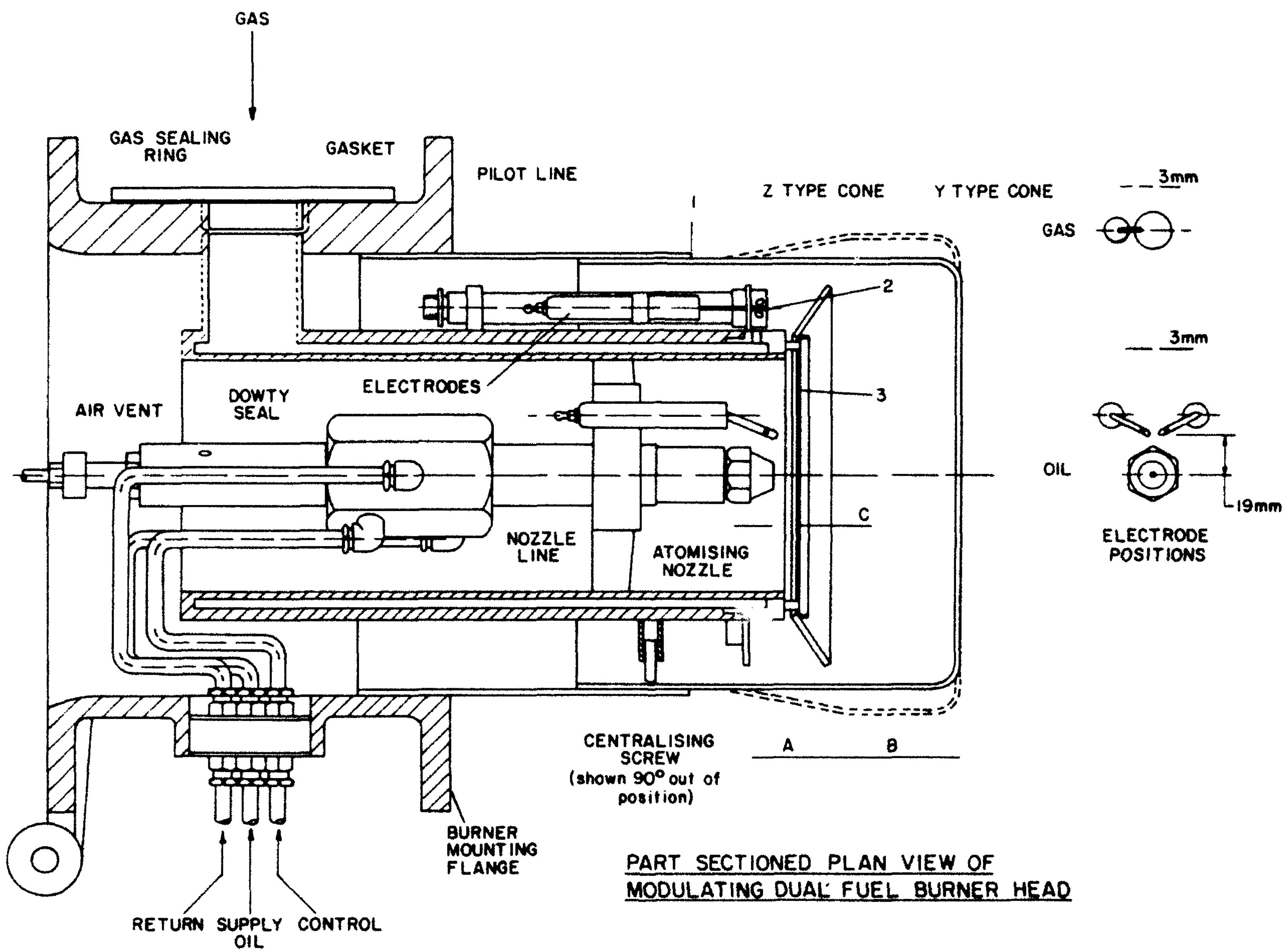


Figure 2. Dunphy TD Series Burner.

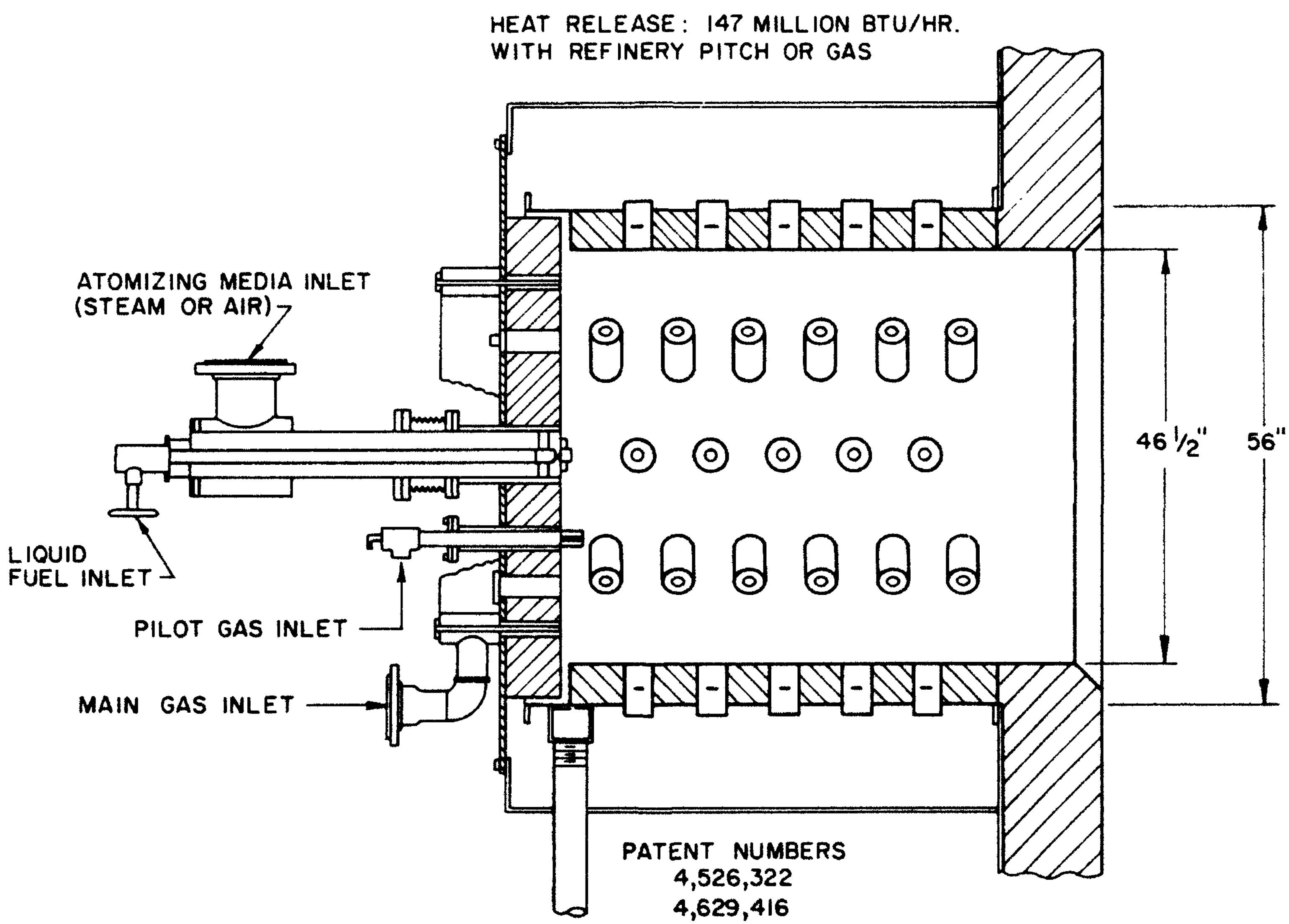


Figure 3. Voorheis Bluff-Body™ Register Burner.

Hague International

Hague's Transjet® Burner (Figure 4) uses high-velocity air supplied through nozzles in the burner housing. This creates a depression at the point of discharge, inducing products of partial combustion to be recirculated and mixed with the incoming combustion air. This "selective recirculation" is said to shape and optimize the mixing process and avoid the complexity of external recirculation ductwork. In addition, the burner uses radial staging with the final 10 to 20 percent combustion air introduced to mix downstream and complete combustion. The center core is operated at an equivalence ratio of 0.7 to 0.9 thereby reducing NO_x formation. The recirculated gas is also said to reduce smoke and allow the burner to operate at low excess air levels across a wide turndown range.

Smit Ovens

The Ultramizing® Multifuel Burner offered by Smit-Ovens uses a tangentially oriented impulse flow of combustion air to atomize oil in an ultrafine dispersion pattern (<10 microns), simultaneously mixing the oil mist with air to generate a stable, bluish, transparent flame similar to natural gas. (Figure 5 illustrates the "Ultramizing" principle.) The unique design of the atomizer maintains the quality of combustion across a wide turndown range. The combustion air quantity is controlled at the Ultramizing Atomizer, providing a near constant air velocity and mixing over the burner turndown. In addition, the high discharge velocity induces partially combusted products into the flame root (internal recirculation) through slots in the burner tile, further enhancing combustion and reducing NO_x formation.

UE Corporation

UE Corporation's ISOMAX® Burner (Figure 6) is said to produce clean blue flames when operating with either oil or gas. It uses the Venturi principle, whereby the combustion air entering the injector nozzle induces recirculation of combustion gases from the flame tunnel through the hot gas return tube. When operating in oil, the oil is injected into the return tube for immediate gasification prior to ignition. The recirculated combustion gases mix and preheat the combustion air, increasing combustion intensity. Combustion is said to be essentially complete within the burner, resulting in very short flames, and no CO or smoke in the flue gases.

Hirt Combustion Engineers

Hirt offered their gas and oil fired Multijet Burner, which is of premix design and is said to provide complete combustion and maximum heat liberation. These burners are available for forced, induced, or natural draft operation. For gas firing, the fuel gas is mixed with the combustion air prior to delivery to the flame holder grid, which consists of a multitude of small openings resulting in multiple jet flames. It appears that, for oil firing, the oil is not premixed, but rather injected through a central nozzle so that it mixes with the combustion air entering the grid within the combustion chamber.

The Engineer Company (TEC)

The Model LX Burner employs a low velocity Venturi air entry to create uniform distribution. This design is said to provide a high-velocity, balanced air stream at the burner throat resulting in efficient penetration and mixing with the fuel streams while minimizing excess air requirements and pollutant generation. To meet the target specifications for maximum NO_x generation, TEC suggested external flue

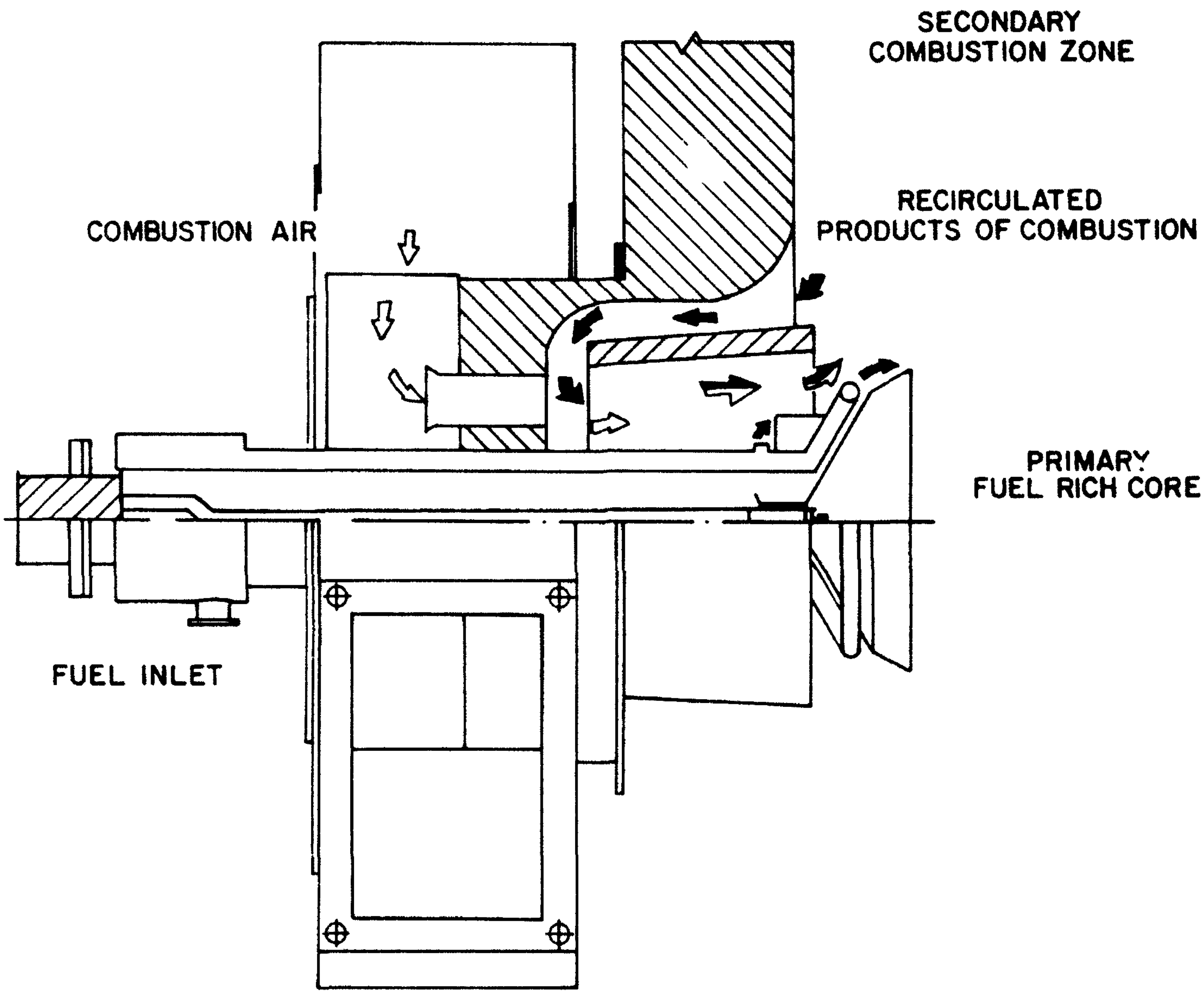
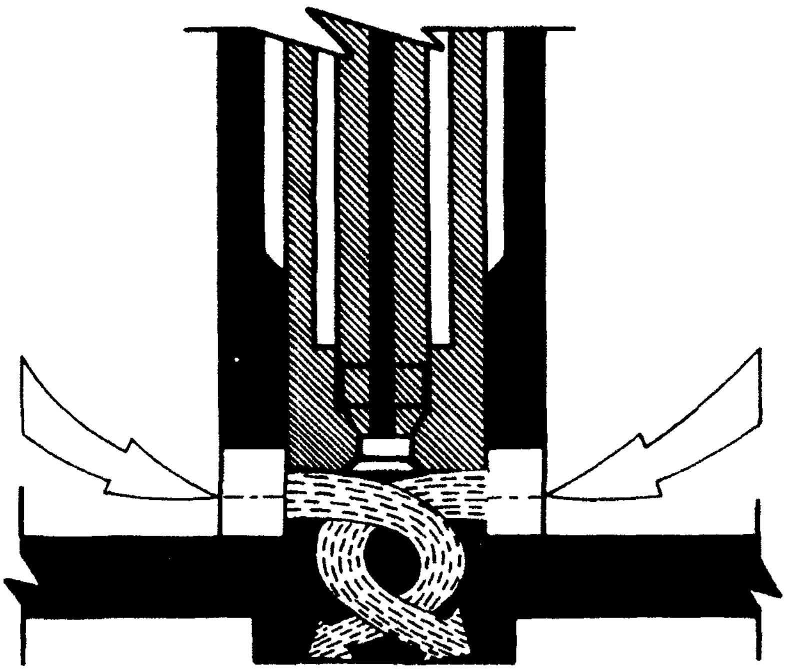
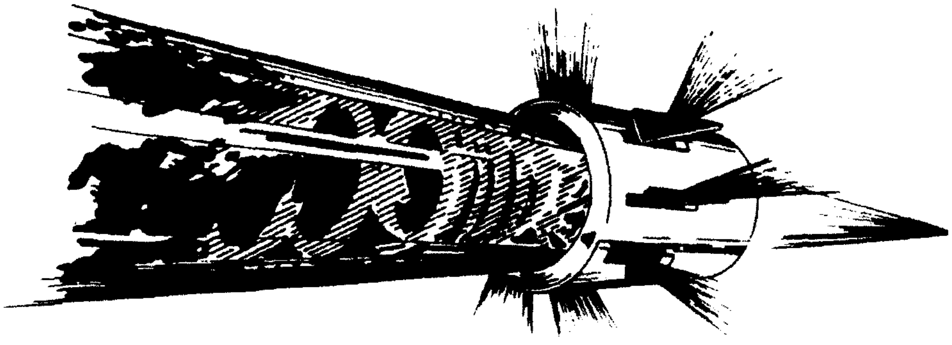


Figure 4. Hague Transjet® Burner.



a. High-capacity atomizing and mixing of fuel and air.



b. Dispersion pattern of oil-air mixture.

Figure 5. Smit Ovens Ultramizing® Burner.

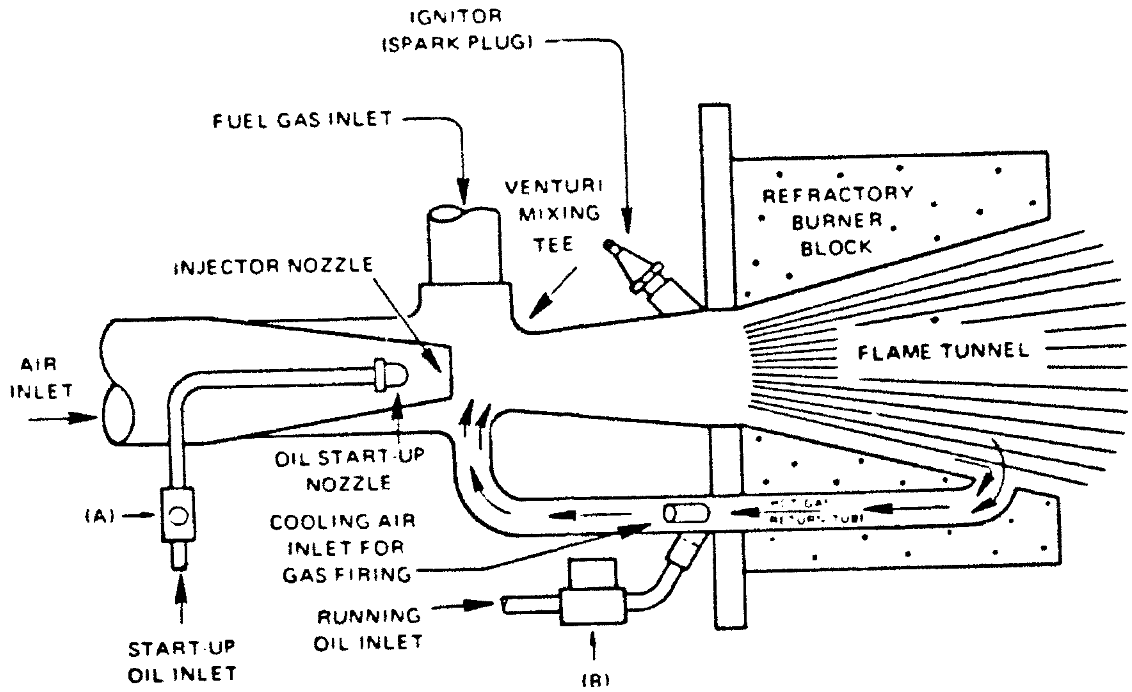


Figure 6. UE Corporation Isomax® Burner.

gas recirculation to decrease thermal NO_x by decreasing the flame temperatures through dilution. Though a viable approach, this would add significantly to the complexity and cost of the retrofit.

John Zink Company

The John Zink Co. recommended their Model HPS-SF/SA Burner, which is of forced draft, axial flow design. For NO_x control, the burner uses fuel staging when firing gaseous fuel, and combustion air staging when firing oil fuel. The fuel staging technique is said to have been proven the best burner design technology for NO_x reduction.

Discussion

Background

Information provided by manufacturers revealed that most of the burners offered were either developed for general applications or for applications other than firetube boilers. In fact, many have never been applied to firetube boilers.

Their spatial restrictions and potential for quenching of flames by "cold" Morison tube walls make firetube boilers demanding applications for burners. Furthermore, the lack of reradiation, compared to a refractory walled combustion chamber, results in relatively "cooler" flames. Thus it is generally difficult to design firetube burners to operate efficiently across the turndown range. Current firetube boiler burners operate at low excess air (high efficiency) only at the nominal capacity, and require a greater amount of excess air at turndown. For example, a burner designed to operate on 10 percent excess air at nominal capacity might require up to 40 percent excess air at 20 percent capacity. At lower excess air levels, NO_x would normally decrease but CO would increase.

Project Burner Technology

The burners solicited in this project were required to: (1) operate with less than 12 percent excess air across a 5:1 turndown for both natural gas and No. 2 oil, (2) produce no more than 50 ppm NO_x (over 50 percent less than the existing levels), and (3) generate very little CO (<50 ppm) and soot (<2 Bacharach). These were stringent, yet realistic requirements. Many burners met most of the target specifications, and the top two burners met them all. The more difficult requirements appear to be the low excess air specification, especially at turndown, and the NO_x emission limit, especially when burning No. 2 oil. Both specifications are critical to satisfy the program objectives of obtaining high-efficiency burner performance and low NO_x and other emissions.

The descriptions of burner technologies give a sampling of the many techniques high-efficiency burners use to obtain low NO_x and excess air operation across the turndown range. Low excess air operation is achieved by improving and maintaining the level of fuel/air mixing over the firing rate range. This is done by increasing combustion air velocity and/or swirl along with more sophisticated and precise mixing arrangements. Recirculation is also used to further enhance combustion efficiency in some burners. Recirculating hot combustion products back into the root of the flame, directly or via combustion air, also appears to be effective in decreasing NO_x emissions. Another industry-accepted technique for decreasing NO_x formation is staged combustion (both fuel and air).

Burner Selection

The top eight burners (Table 5) were selected based on specification data provided by manufacturers. Researchers recognized that some of these data were based on estimations rather than actual measurements, especially emissions data. Since many of the burners were not developed specifically for firetube boilers, the reported data was probably acquired in applications that may be only partly applicable to firetube boilers. For example, a burner operated on firetube boilers should produce less NO_x emissions than one operated on refractory walled combustion chambers. A burner operated on firetube boilers should also test somewhat worse in terms of excess air requirements and CO and UHC emissions because, in firetube boilers, the higher heat transfer to the cooler Morison tube results in cooler flames (lower NO_x), and a much greater potential for flame quenching that results in incomplete combustion.

After discussing the specifications for each of the eight burners in detail along with their potential to meet these specifications, their applicability to firetube boilers, and their costs, the following three burners were selected as candidates for field testing: the Dunphy TD Series, the Hague Transjet®, and the UE Isomax®.

4 TEST SETUP

Researchers visited three sites (the Yakima Firing Center in Yakima, WA; Fort Knox Army Base in Fort Knox, KY; and the Louisiana Army Ammunition Plant in Shreveport, LA) to investigate the potential for field testing the selected burners. Nontechnical factors that surfaced during the burner survey determined that the best combination would be to test the UE Isomax® Burner at Yakima, the Dunphy TD Burner at Fort Knox, and the Hague Transjet® Burner at the Louisiana plant. Each site had three identical boilers. The first was to be tested in original configuration; the second was to be tested with the new burner; and the third with the new control system.[2]

Site Specifications

Of the three visited sites, two (the Yakima Firing Center and Fort Knox Army Base) were selected for the demonstration based on their typical Army characteristics, the selected burners, and the demonstration strategy. (After this study had begun, the Louisiana plant was scheduled for shutdown.) The demonstration strategy required each site to have at least two identical Boilers for a side-by-side comparison of conventional and high-efficiency, low-NO_x burners. The performance test plan included long-term monitoring of boiler efficiency and short-term performance tests for combustion efficiency and NO_x emissions. At the time of this report, long-term testing had been initiated at both sites and one short-term test had been completed at one installation.

Yakima Firing Center (YFC)

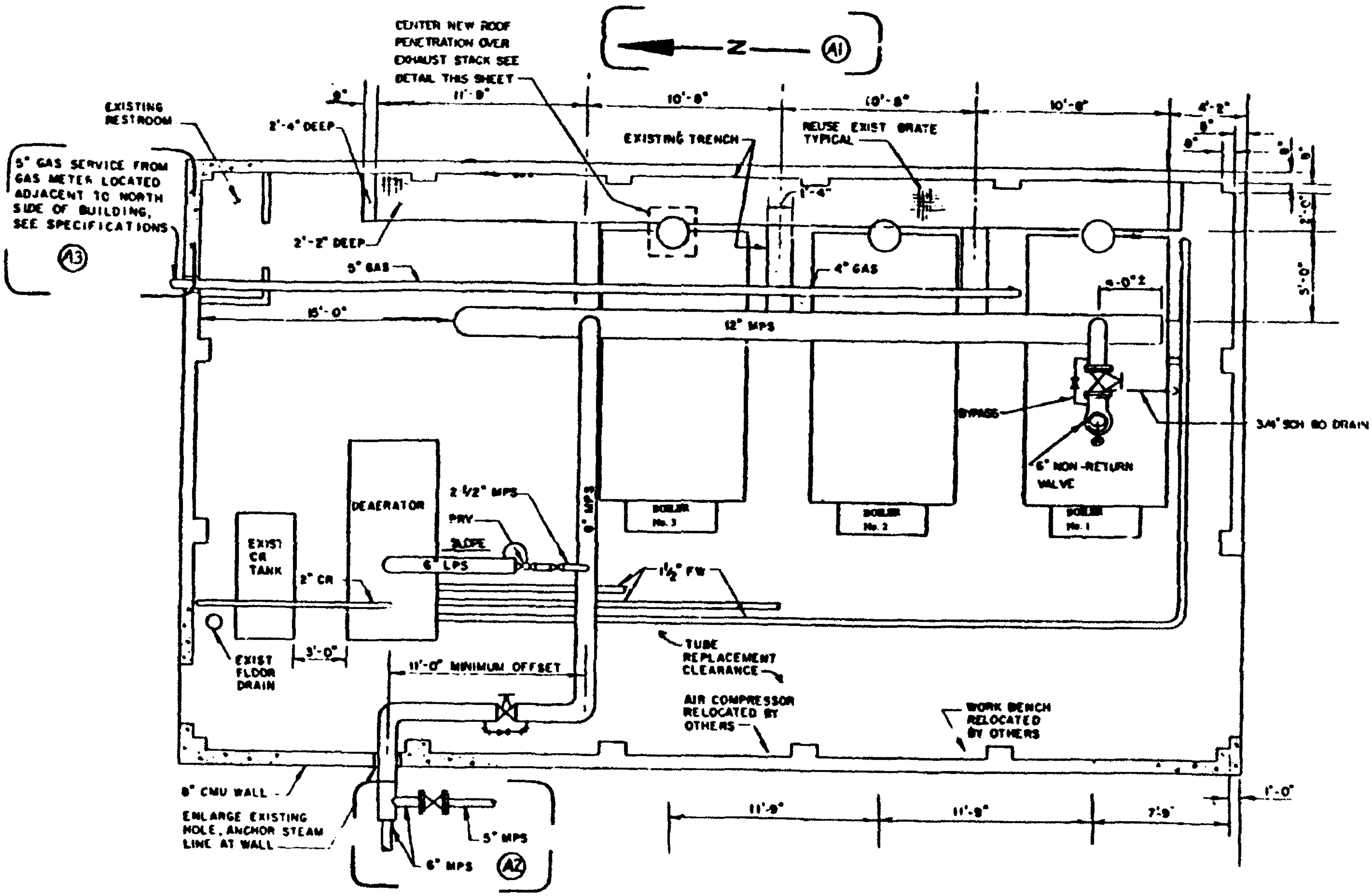
Building 223 at YFC provides steam for space heating and domestic hot water for barracks, mess halls and offices. The boiler house at Plant 223 contained three identical, relatively new, Kewanee Classic III, 300 hp Scotch marine firetube steam boilers that had been installed in 1984 (Figure 7). All three boilers were equipped with Kewanee Series F dual-fuel package burners (Figure 8) for firing natural gas or No. 2 oil. The boilers were also equipped with Westinghouse O_2 trim controls for air/fuel ratio regulation, which were adapted to the new burner. The natural gas flow rate was measured by a single totalizing meter on the main supply line, and the oil flow was measured by totalizing meters on individual boilers.

The UE Isomax® could not be configured to fit the YFC Boiler No. 1. Based on the system design and boiler arrangement, and since the Louisiana plant site was no longer available, Boiler No.1 was retrofitted with a "Hague Transjet®." The new O_2 trim system was tested on Boiler No. 2. Boiler No. 3 was designated for the conventional burner test.

Fort Knox Army Base

The Fort Knox demonstration was located at Building No. 1483, which provides steam for space heating and domestic hot water for a mess hall and dormitories. The boiler room has three Kewanee Classic III, 200 hp, low-pressure steam boilers that were built in 1979. The boilers were equipped with Kewanee Series F package burners. Boiler No. 1 was designated for the conventional burner test, and Boiler No. 2 was retrofitted with the "Dunphy TD 37 YMH" burner.

[2] Noel Potts, *Technical Support for the Selection and Supply of Microprocessor Combustion Controllers for Dual Fuel Package Boilers*, Draft Technical Report (U.S. Army Construction Engineering Research Laboratory [USACERL], December 1991).



PLAN
SCALE: 1/4" = 1'-0"
(EXISTING PIPING NOT SHOWN)

Figure 7. Boiler Arrangement at the Yakima Firing Center.

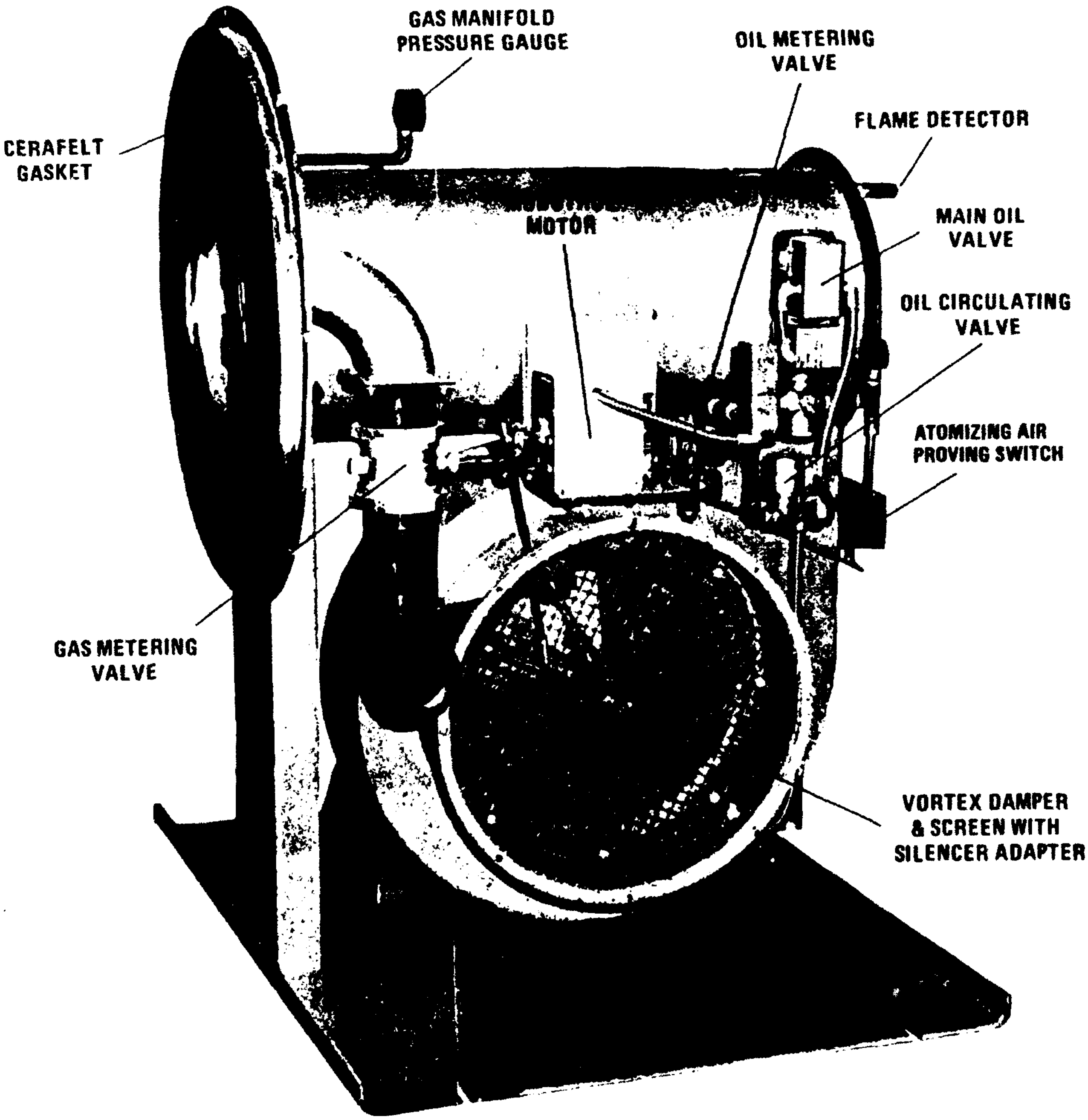


Figure 8. Kewanee Series F Dual-Fuel Package Burner.

The boiler room in Building No. 1483 at the Fort Knox base had three identical Kewanee Classic III, 200 hp, 150 psi steam boilers manufactured in 1979 (Figure 9). The boilers were equipped with Kewanee Series F package burners. Boiler No. 1 was set up for gas firing with no oil train, and Boilers No. 2 and No. 3 were set up for oil firing with no gas trains. The Dunphy burner was tested on boiler No. 2, the new air/fuel controls were installed on Boiler No. 3 and the test boiler, No. 1 with its original burner/control configuration.

Site Preparation

Identical dual-fuel package boilers were located at YFC and Fort Knox. Each pair was serviced to ensure proper operation and equal baseline performance. One boiler of each pair was equipped with a high-efficiency, low-NO_x burner for comparison with its companion conventional boiler for performance, reliability, and maintenance. Monitoring instrumentation was installed and data was collected for burner evaluation. All four boilers were inspected, cleaned, and tuned before the test program was initiated. No unusual problems were noted. However, a few problems occurred during shakedown and initial operation.

Yakima Firing Center—Hague System

Preparations at the boiler house for field testing included the following major items:

1. Checking the existing safety controls on all test boilers

2. Installing a new burner manufactured by Hague International on Boiler No. 1 as per burner manufacturer's specifications and drawings

3. Connecting the new burner on Boiler No. 1 to plant controls

4. Restoring Boiler No. 3 to conventional burner configuration per Kewanee specifications

5. Installing individual gas flow meters

6. Modifying the steam piping outside the boiler plant to allow steam venting from a muffled exhaust valve

7. Providing an opening in the stacks for boiler exhaust gas temperature and emission monitoring

8. Cleaning all boilers.

The nominal capacity of the Hague Transjet® at YFC is 15 MBtuh input, but its nameplate rating is 12.5 MBtuh input of natural gas or No. 2 fuel oil. Current uncalibrated measurements while burning natural gas have shown NO_x at 50 ppm for this burner compared to 75 ppm for Kewanee burners on the other boilers.

In the Hague Transjet® burner, furnace gas rather than flue gas is internally recirculated. The recirculated gas encapsulates the flame in a sheath with little or no recirculation occurring at the center of the flame front. Combustion air is supplied from an integral windbox through nozzles in the burner housing. This high velocity creates a depression at the point of discharge and induces products of combustion to be recirculated and mixed with the incoming combustion air. A sheath of combustion air and recirculated gas surrounds and mixes with the fuel-rich core flame to complete combustion as the flame travels down the furnace. The manufacturer specifications indicated NO_x levels of 40-50 ppm and a 10:1 turndown ratio with natural gas, and 45-50 ppm NO_x and a turndown ratio of 8:1 for No. 2 oil.

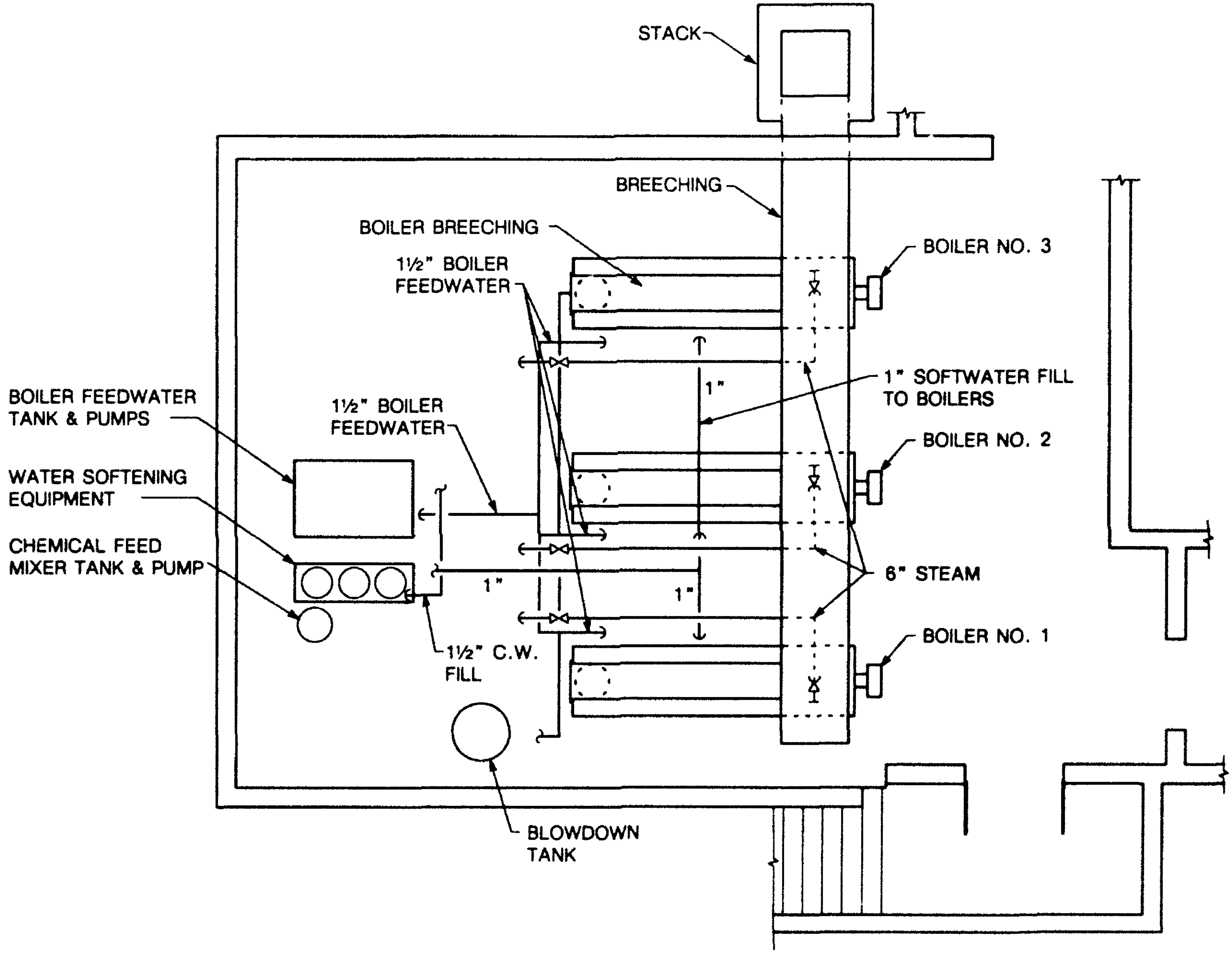


Figure 9. Boiler Arrangement at Fort Knox

After three site visits and one burner replacement by Hague (the last visit being in March 1990), the burner was still not fully operational. Even basic burner operation could not be achieved because of improper connection to the existing plant and boiler controls. During his attempt to complete connection to existing controls, the Hague serviceman cited faulty controls, faulty safety devices, inaccurate drawings, and inaccurate wiring identification. He made many changes to existing wiring and wiring identification tags.

To resolve these problems, USACERL tasked an independent controls specialist to:

1. Make necessary alterations in wiring and controls for burning oil. These alterations should allow for use of the plant air compressor rather than the existing compressor at Boiler No. 1 to supply atomization air.

2. Check operation and wiring of safety devices in the burner's gas and oil train, steam pressurestats, low water cut-off device, and the Fire-eye combustion monitor. Check the position and the installation of the flame detector for adequate flame view, and correct any deficiencies found.

3. Correlate the feedback/control between the submaster for Boiler No. 1 at the main plant control panel, the Fire-eye, and the fuel valve operator on the burner.

4. Direct the adjustment of fuel/air linkage for best combustion of both oil and gas. USACERL provided a combustion analyzer to generate information and made the actual adjustment.

5. Direct the adjustment of the Hague air/fuel trim system. USACERL provided a combustion analyzer and made actual adjustments.

6. Attach identification numbers to all associated wires at all junction points after achieving successful control of the Hague burner. Provide sketches or mark existing drawings to show final arrangement of controls and wiring, including wire identification numbers.

This demonstration site is not yet fully functional. The manufacturer's service representatives have thus far achieved only performance equal to conventional burners while firing natural gas. Oil firing has been unsuccessful. Further adjustment of the burner using factory improved replacement parts is planned.

Fort Knox Dunphy System

Preparation for field tests of the Dunphy burner included:

1. Adding a gas train to Boiler No. 2 and to the existing oil fired burner on Boiler No. 1

2. Installing a new Dunphy burner on Boiler No. 2 per manufacturer's specifications and drawings including those on the burner mounting flange (Dunphy was contacted to provide information.)

3. Installing individual oil flow meters

4. Installing individual gas flow meters

5. Modifying steam piping to allow steam venting

6. Providing openings in stacks for temperature and emission monitoring

7. Cleaning all boilers.

The Dunphy burner at Fort Knox uses an axial turbine fan to force combustion air through swirl chambers for optimum air distribution. The air quantity is controlled by a cylindrical drum with slots that rotates axially in front of another identical concentric stationary drum. Gas and oil flow are corrected for variance in combustion air conditions by pressure balanced valves with pneumatic sensor lines for gas, oil, and combustion chamber pressures. In the combustion chamber, a characterized gas ring or oil gun creates fuel rich pockets that later mix with additional air for complete combustion and NO_x reduction. The manufacturer specifications indicated NO_x levels of 28-38 ppm and a 4:1 turndown ratio with natural gas, and 36-41 ppm NO_x and a turndown ratio of 4:1 for No. 2 oil.

During on site visits to make final burner adjustment, Dunphy performed the following:

1. Inspected the burner installation, and directed and assisted in the required corrections to the burner installation, approved the burner installation for firing, and fired and adjusted the burner for safe, optimum performance on both natural gas and No. 2 fuel oil

2. Marked burner adjustment settings to ensure that the burner remained at its optimum performance

3. Instructed three Fort Knox boiler operators at the boiler plant in proper burner operation and maintenance

4. Provided Fort Knox with literature covering operation and maintenance for any new features on the burner.

The Fort Knox demonstration experienced three problems during the long-term test period. The first problem occurred on the weekend of 15 April 1989 and was related to the flame safety control that was manufactured for European instead of U.S. voltage. Fort Knox personnel suspected a poor connection in the burner sequencer had overheated and ruined the contact. They made a temporary fix and steadily operated the burner until 5 September 1989 when the problem repeated and the module could no longer be repaired. This problem was corrected by installing replacement parts recommended by the burner manufacturer.

The second problem was a warped diffuser plate. This problem was caused by an incorrect specification that overlooked the boiler's negative furnace pressure. The diffuser plate was replaced with the correct design.

The last problem was the failure of the gas valve operator after only 10 months of operation. The manufacturer supplied a new gas valve operator in January 1990 to replace the failed operator. Based on the failure rates of similar valve operators, this was an unusual failure.

Monitoring

The demonstration sites were selected on the availability of two identical boilers for side by side comparison of hi-efficiency to conventional burners. The test plan included long-term monitoring of boiler efficiency and short term testing for combustion efficiency and NO_x emissions. The objective of long-term monitoring was to compare boiler efficiency for normal operation and maintenance conditions. Results of the performance comparison will determine cost savings, reliability, applicability to Army facilities, maintenance requirements, and operational efficiency of the tested burners. At the end of the monitoring period, monitoring equipment will be removed, and boiler equipment will be returned to equal or better than "as found" condition.

Long-term monitoring of input-output efficiency parameters was accomplished remotely using an "Acurex Autograph 800" data acquisition system. The Acurex collects, compiles, and stores the necessary data, which is later downloaded telephonically to USACERL's computer. The system collects data for feedwater flow, feedwater temperature, and fuel flow (natural gas and No. 2 oil), corrected to standard conditions. The feedwater flow was determined to be more accurate than steam flow for measuring boiler output. The boiler efficiency was calculated from these measurements.[3]

A series of short term tests are being performed on-site to evaluate burner performance throughout its operating range. These tests sample stack flue gas for concentrations of oxygen, carbon monoxide, nitrogen oxides, combustibles, and temperature. Flue gas measurements are made using an Enerac 2000 flue gas analyzer. The gas sensors are electrochemical cells and the combustibles sensor is a semiconductor. Prior to each test, the analyzer is calibrated with reference gases for O_2, CO, and NO_2. The fuel input and combustion air temperature are also measured. Combustion efficiency is calculated using the heat-loss method.

[3] G. Maples, D. Dyer, and M.J. Savoie, *U.S. Air Force Central Heating Plant Tuneup Workshop, Volume XI: Efficiency*, Special Report (SR) E-90/03/ADB141661 (USACERL, January 1990).

5 ECONOMIC ANALYSIS

The financial value of any technology that improves boiler efficiency can be calculated and used to determine if the added value will offset the cost of implementation. One manner to measure this value is by computing the extra or marginal output produced by the technology. The dollar value of this extra output can be calculated by multiplying the marginal Btu/yr by the cost per unit of fuel.

For high-efficiency boiler technology, this value translates into lower fuel costs resulting from increased output. Calculations were performed for three different fuel prices to illustrate the impact on the analysis of rising or falling fuel costs (Figures 10 through 15). The Btu/yr output of a boiler can be estimated by:

$$\begin{aligned} \text{Btu/yr} = {} & \text{Efficiency Factor (\%)} \times \text{Boiler Size (hp/hr)} \\ & \times 365 \text{ days} \times 24 \text{ hr} \times \text{Load Factor (\%)} \end{aligned} \qquad \text{[Eq 1]}$$

The extra boiler production results from the higher efficiency factor shown in the above equation. The fuel cost savings produced over a given time span can be compared to the initial cost of the technology to estimate an acceptable discounted payback period for the technology. A payback period represents the amount of time (in years) in which a project will recoup the initial investment (i.e., break even). All benefits occurring beyond the payback period date are considered to be profit. The payback period is computed by dividing the cost of the project by the dollar return per year. A discounted payback period introduces the time value of money and forces the analysis to consider a rate of interest or the "cost of money" associated with borrowing the funds needed to finance the project, or with the "opportunity costs" of being unable to invest these funds elsewhere for a given rate of return. The discount rate used throughout this analysis is 10 percent.

The factor used in this analysis to measure the benefit of the technology is a 3-year discounted payback period. Figures 10 through 15 show the "percentage of additional boiler efficiency" (the horizontal axis) measured against a "3-year payback value" (the vertical axis). To measure the value of a 5 percent gain in efficiency, for example, locate 5 percent on the horizontal axis and then use the appropriate fuel cost curve to locate the dollar amount (in thousands) on the vertical axis. This amount represents the technology's maximum cost that will still produce a 3-year discounted payback period at a 10 percent discount rate. Figures 10 to 15 show that, as fuel costs rise, the dollar value of the technology also rises. The value of the technology also rises with load-factor increases, and linearly with increases in the horsepower of the boiler.

Although this analysis accurately captures the cost associated with fuel savings, it does not address the problems of emissions, differential operation and maintenance costs, and service life associated with the technology. Whether the new technology can help resolve these problems must be considered along with fuel savings in determining project acceptability.

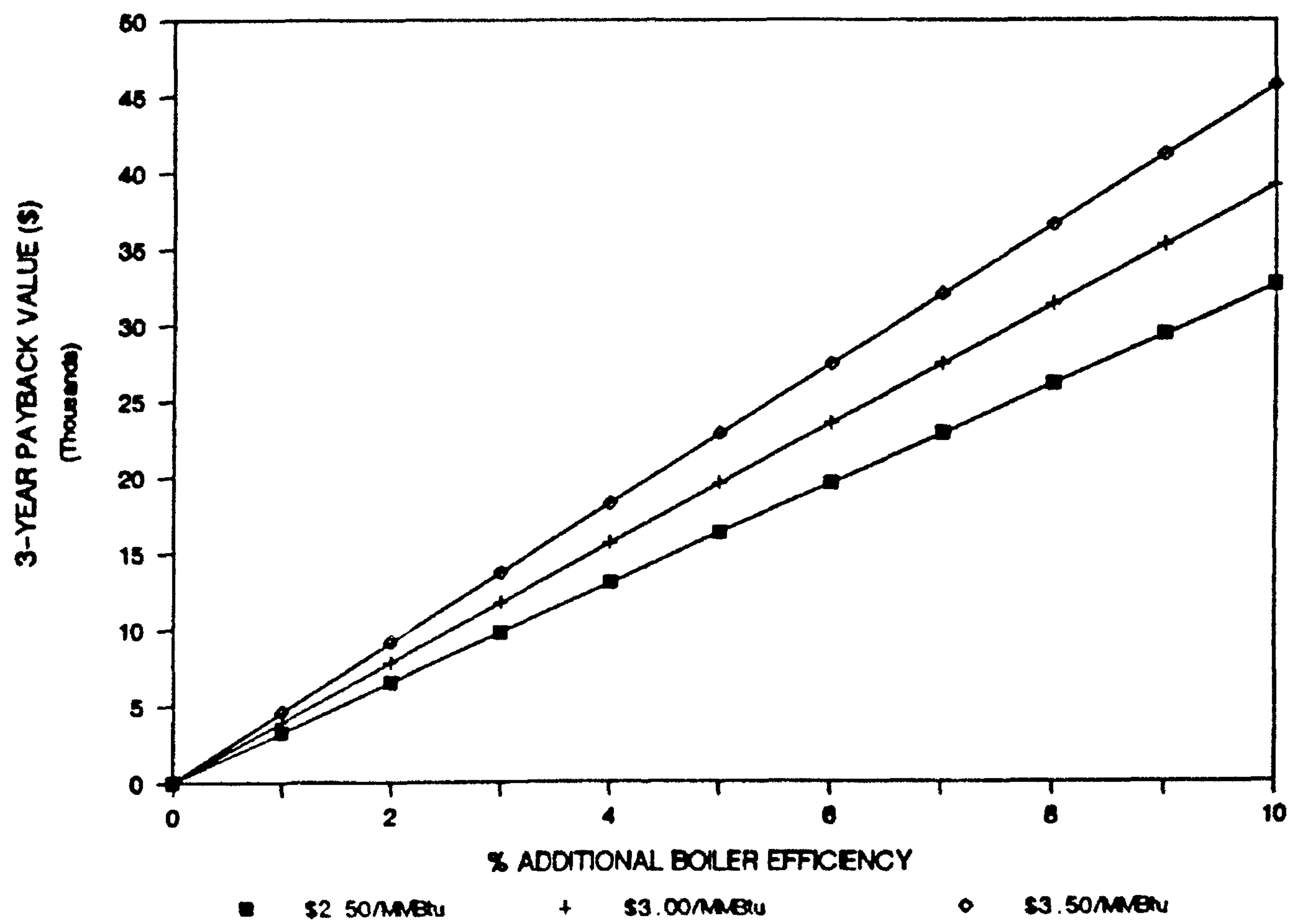


Figure 10. Value of Increased Boiler Efficiency at 3-Year Payback Value Given 60% Load, 250 hp, 80% Efficiency.

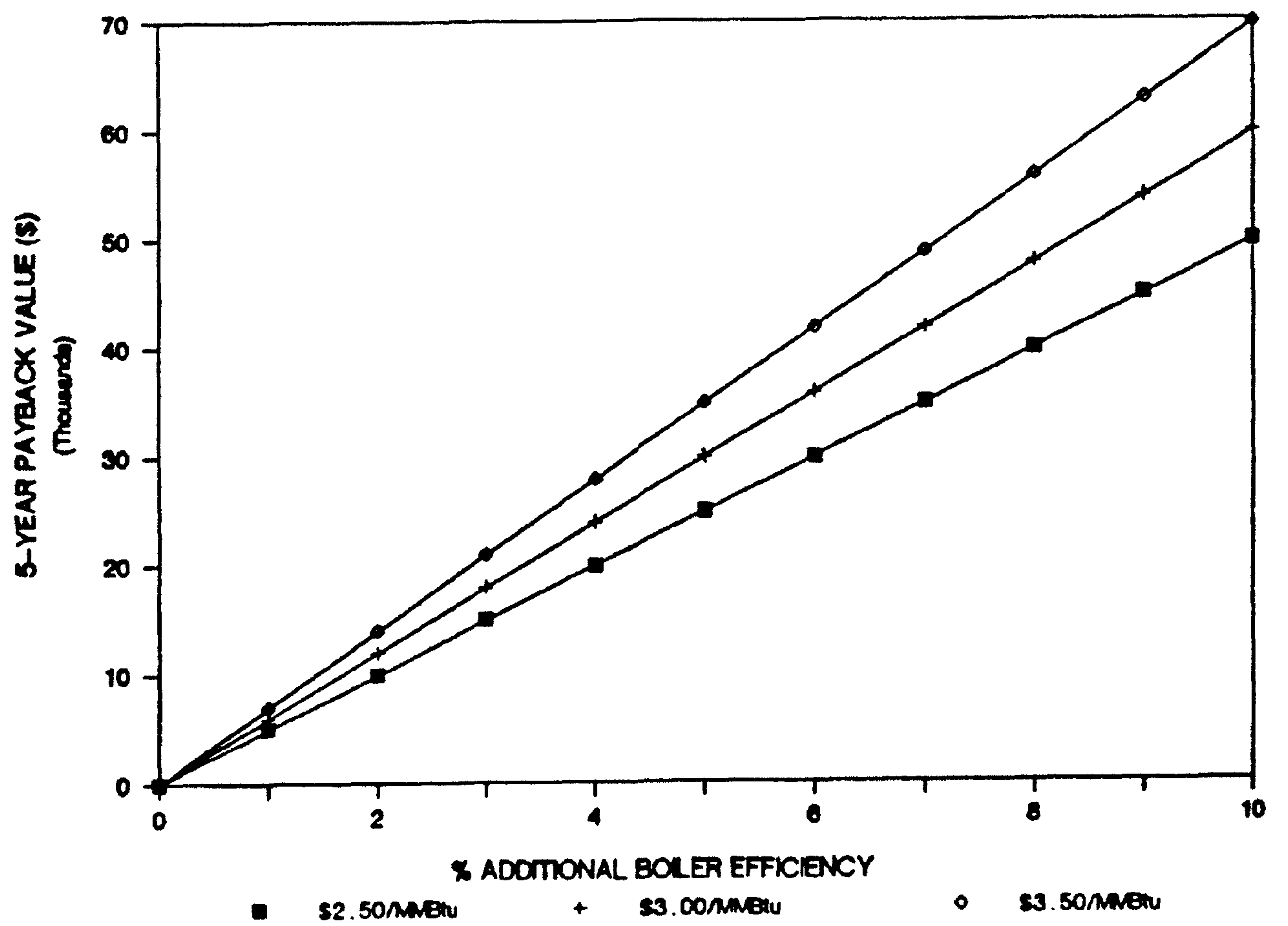


Figure 11. Value of Increased Boiler Efficiency at 5-Year Payback Value Given 60% Load, 250 hp, 80% Efficiency.

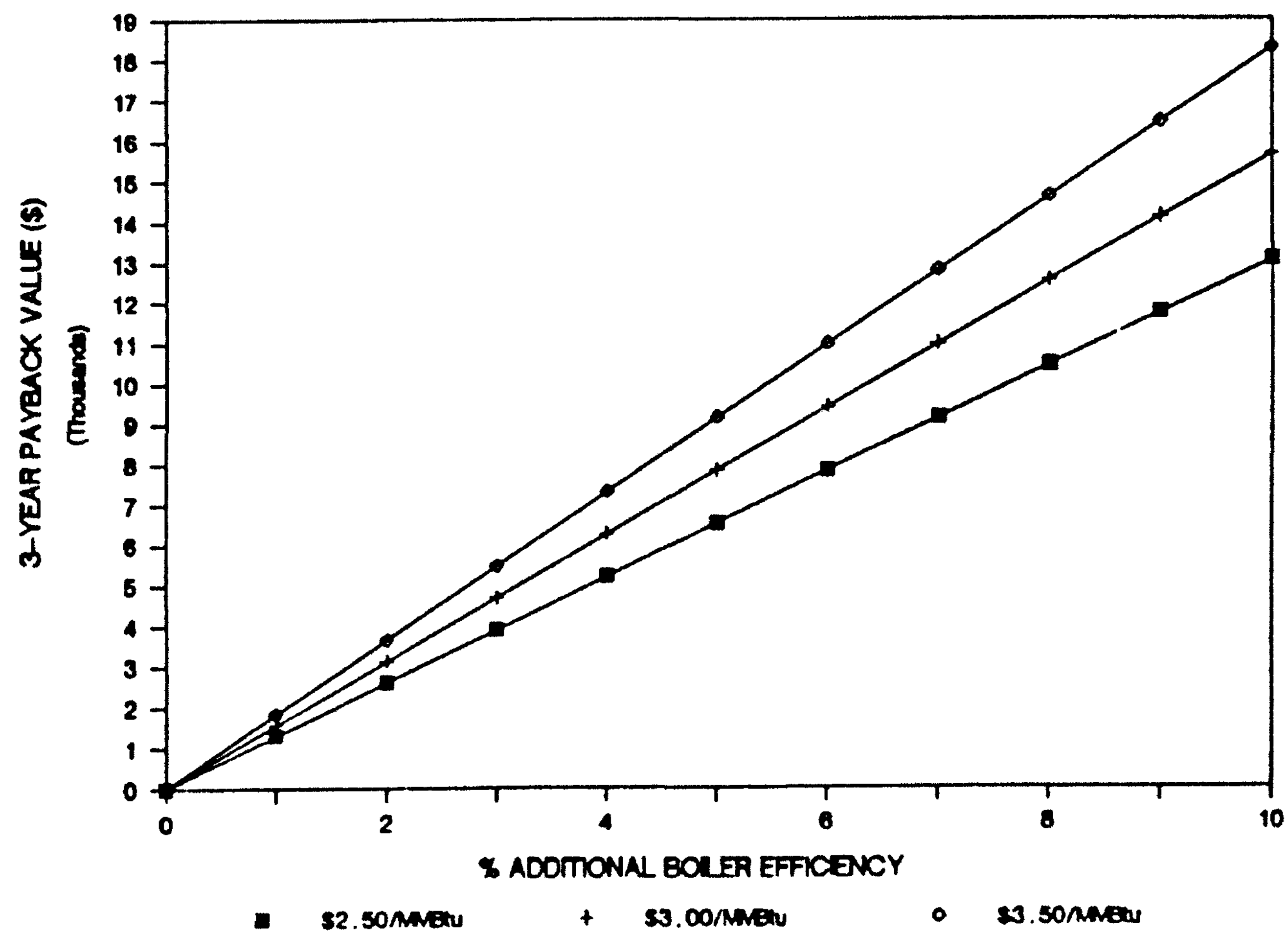


Figure 12. Value of Increased Boiler Efficiency at 60% Load, 100 hp, 80% Efficiency.

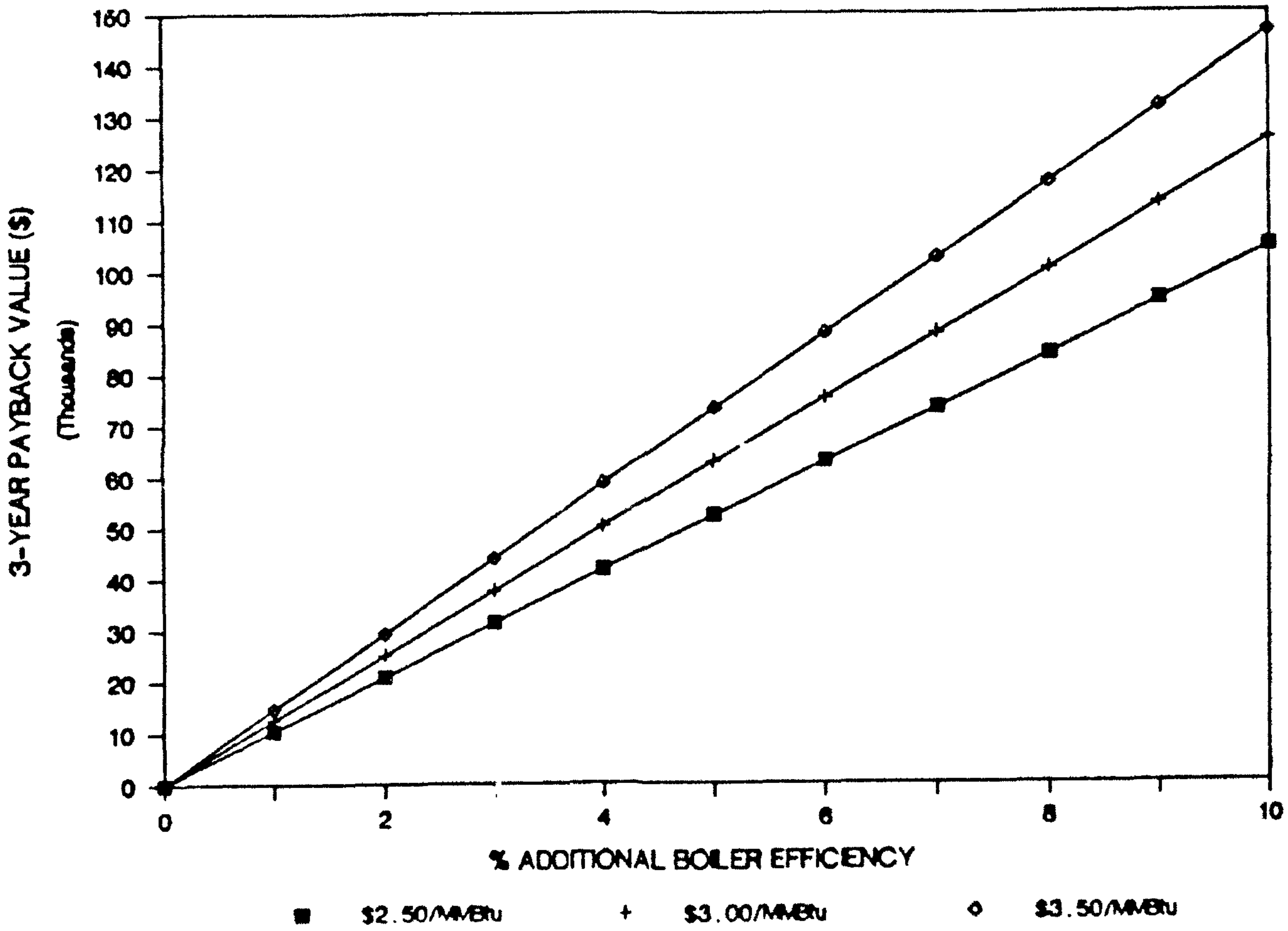


Figure 13. Value of Increased Boiler Efficiency at 60% Load, 800 hp, 80% Efficiency.

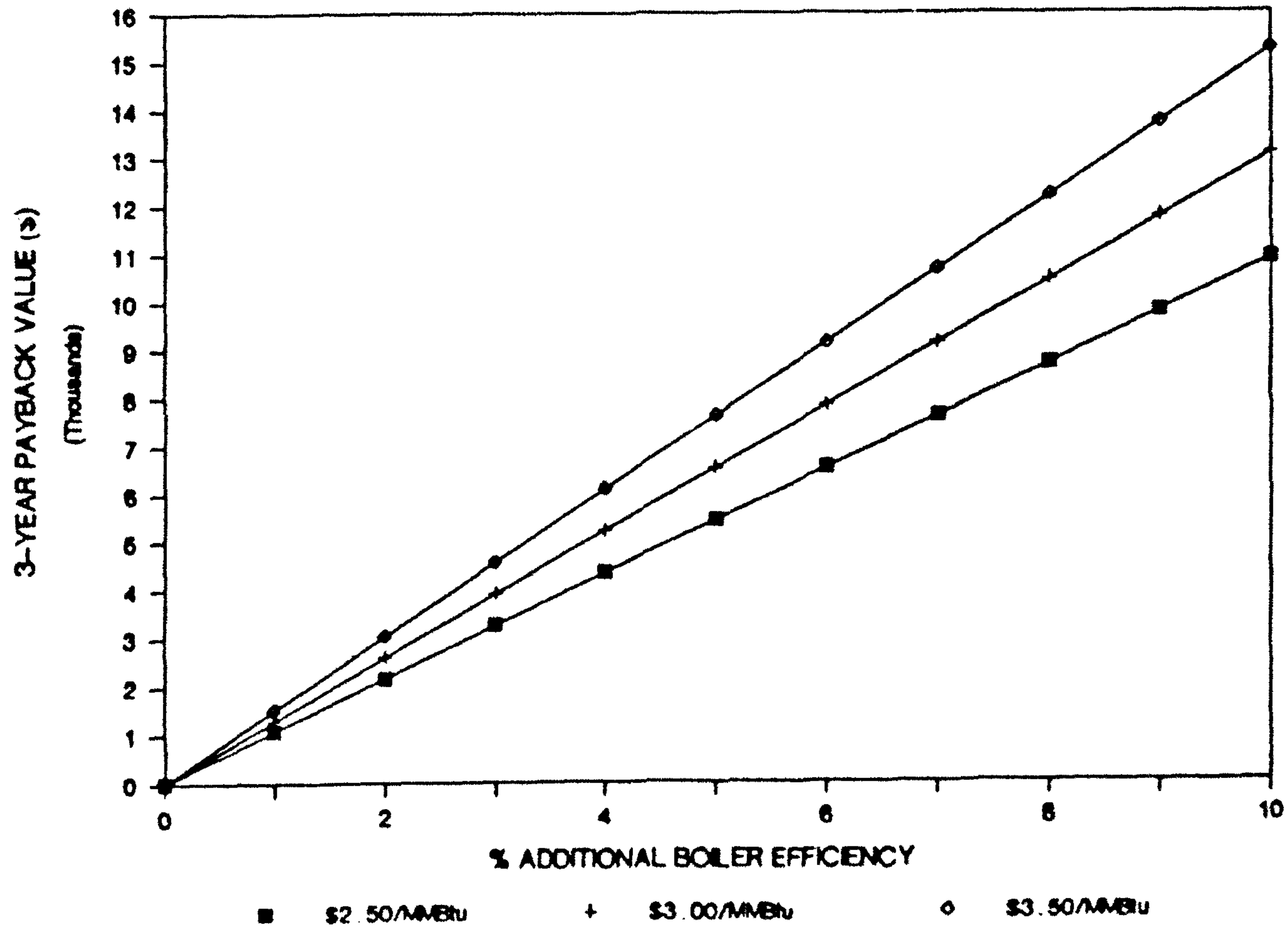


Figure 14. Value of Increased Boiler Efficiency at 20% Load, 250 hp, 80% Efficiency.

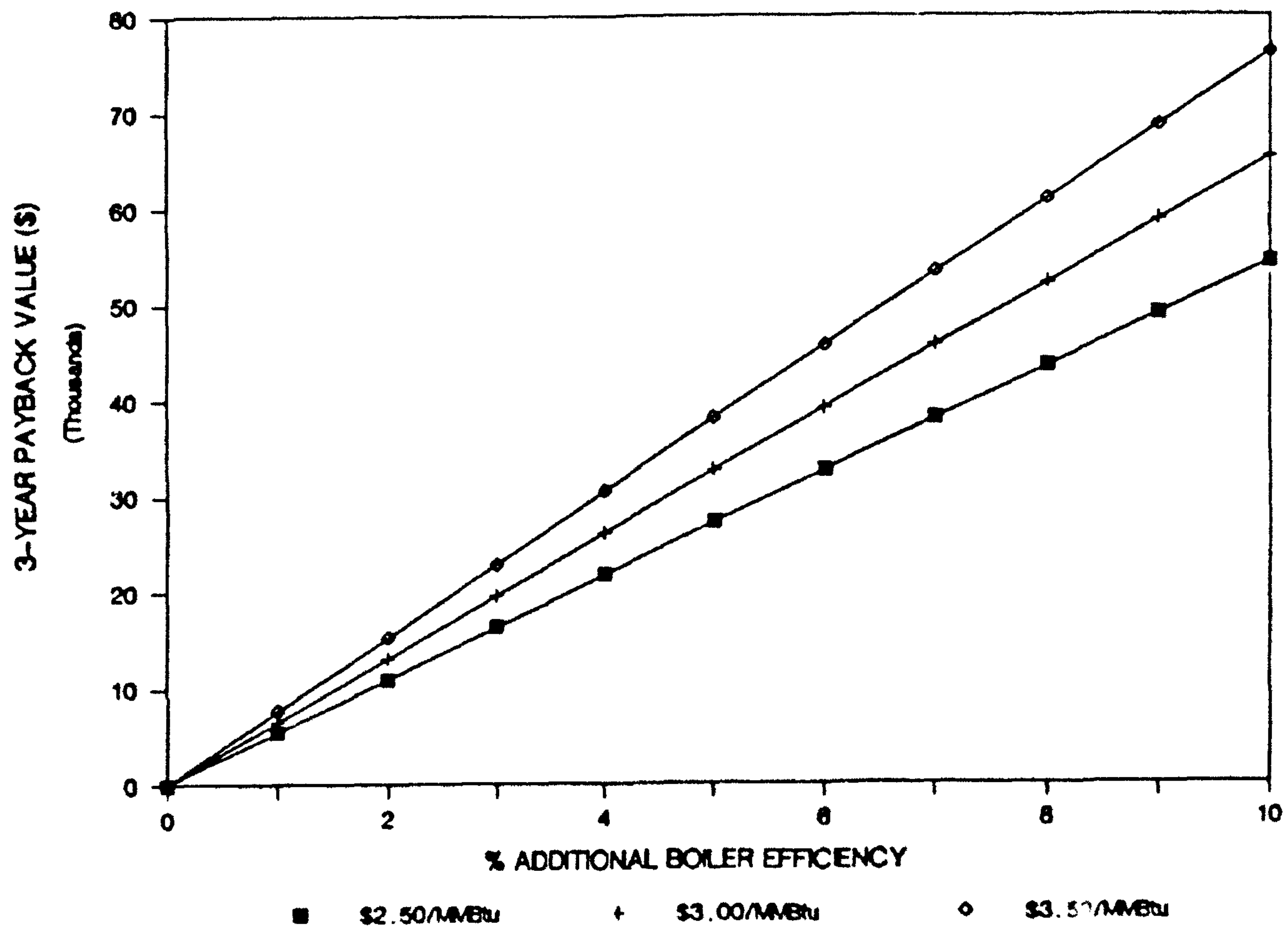


Figure 15. Value of Increased Boiler Efficiency at 100% Load, 250 hp, 80% Efficiency.

The value of the high-efficiency burner can be determined by comparing the estimated capital cost of the system to the expected fuel savings predicted by the boiler efficiency analysis. The manufacturers' quotes for the selected equipment are:

Dunphy burner package:	$10,000
	$10,000
Hague burner package:	$27,900
Hague O_2 control:	$ 5,400
	$33,300

Equipment installation is estimated to cost about $4,000. Thus, the installed capital cost is $14,000 for the Dunphy equipment and $37,300 for the Hague equipment. Figures 10 through 15 show that at this cost the project is economically acceptable with the Dunphy equipment but largely unacceptable with the Hague equipment. Figures 10 through 15 predict a 4 percent improvement in efficiency to be worth $13,000 and $17,000 depending upon the cost of fuel, under conditions of a 3-year maximum payback, and assuming a 60 percent load factor and a 250 hp boiler. A 5-year payback period will produce an acceptable expenditure range of $19,000 to $25,000. Under these conditions, implementation of the high-efficiency burner allows a 4 percent improvement to be worth $40,000 to $55,000 on an 800 hp boiler, and $5,000 to $7,000 on a 100 hp boiler. Should the load factor on a 250 hp boiler increase to 100 percent or decrease to 20 percent, the acceptable expenditure ranges would become from $21,000 to $29,000, or from $4,000 to $6,000.

6 RESULTS

Preliminary Test Results

At present, the long-term test data is being collected from both the Yakima and Fort Knox sites. Data collection is incomplete, pending improvement of test burner performance at Yakima. The complete long-term data set has yet to be analyzed.

The first short-term test was conducted at the Fort Knox site on 17-18 April 1990. Tables 6 through 9 and Figures 16 through 18 show the results of this test. NO_x emissions were corrected to 3 percent oxygen as required by SCAQMD emission regulations.

Table 6

Fort Knox—Conventional Burner Test

	Load %	O_2 %	CO ppm	NO_x ppm	NO_x ppm*	Comb. %	Temp °F**	Fuel MBtu/h	Comb. Eff.
Natural Gas									
	31	6.0	0	77	92	0	262	2.43	84.9
	52	4.5	0	90	98	0	290	4.15	84.6
	74	3.3	6	103	105	0	309	5.90	84.4
	96	2.0	39	106	100	0.04	320	7.60	84.4
No. 2 Oil									
	31	6.9	0	77	98	0	233	2.30	89.5
	54	5.5	0	90	105	0	290	4.05	88.5
	76	4.6	0	116	127	0	300	5.72	88.6
	99	3.9	6	135	142	0	310	7.47	88.5

*Corrected NO_x to 3% O_2.
**Ambient temperature = 79 °F.

Table 7

Baseline Emissions Testing

	Load	O_2 %	CO_2 %	CO ppm	NO_x* ppm	NO_x ppm*	Comb. %	Stack Temp °F**	Fuel MBtu/h
Natural Gas	MIN	6.0	8.4	0	77	92	0	262	2.43
	1/3	4.5	9.2	0	90	98	0	290	4.15
	2/3	3.3	9.9	6	103	105	0	309	5.90
	MAX	2.0	10.7	39	106	100	0.04	320	7.60
No. 2 Oil	MIN	6.9	10.4	0	77	98	0	233	2.30
	1/3	5.5	11.6	0	90	105	0	290	4.05
	2/3	4.6	12.2	0	116	127	0	300	5.72
	MAX	3.9	12.8	6	135	142	0	310	7.47

*Corrected NO_x to 3% O_2 = measured NO_x $\frac{(20.9 - 3.0)}{20.9 - O_2}$

**Ambient temperature = 79 °F.

Table 8

Fort Knox—Dunphy Burner Test

	Load %	O_2 %	CO ppm	NO_x ppm	NO_x ppm*	Comb. %	Temp °F**	Fuel MBtu/h	Comb. Eff.***
Natural Gas									
	21	4.3	3	59	64	0.03	221	1.64	86.5
	45	1.4	40	66	60	0.09	307	3.53	85.0
	69	1.7	8	70	65	0.03	320	5.43	84.7
	93	1.3	8	75	68	0.04	329	7.38	84.6
No. 2 Oil									
	17	7.3	8	60	79	0.53	290	1.28	88.2
	48	4.8	13	98	109	0.68	303	3.59	88.7
	74	4.8	11	112	124	0.86	331	5.65	87.9
	104	3.7	13	120	120	0.69	342	7.92	88.0

*Corrected NO_x to 3% O_2.
**Ambient temperature = 88 °F.
***Boiler not at steady state.

Table 9

Dunphy Emissions Testing

	Load	O_2 %	CO_2 %	CO ppm	NO_x ppm	NO_x ppm*	Comb. %	Stack Temp °F**	Fuel MBtu/h
Natural Gas	MIN	4.3	12.5	3	59	64	0.03	221	1.64
	1/3	1.4	14.6	40	66	60	0.09	307	3.53
	2/3	1.7	14.4	8	70	65	0.03	320	5.43
	MAX	1.3	14.6	8	75	68	0.04	329	7.38
No. 2 Oil	MIN	7.3	10.4	8	60	79	0.53	290	1.28
	1/3	4.8	12.0	13	98	109	0.68	303	3.59
	2/3	4.8	12.1	11	112	124	0.86	331	5.65
	MAX	3.7	12.9	13	115	120	0.69	342	7.92

*Corrected NO_x to 3% O_2 = measured $NO_x \; \frac{(20.9 - 3.0)}{20.9 - O_2}$

**Ambient temperature = 88 °F.

Preliminary test data does not show a significant improvement in combustion efficiency for either natural gas or No. 2 oil. This was expected for No. 2 oil because there was no significant change in excess air levels. However, operation on natural gas does show substantially lower excess air levels obtained by the Dunphy burner and an improvement was expected.

The test does show a 35 percent reduction in NO_x while burning natural gas, a drop from about 99 to 64 ppm. However, this still falls short of the 28-38 ppm indicated in the Dunphy specifications. There was no significant change in NO_x while burning No. 2 oil.

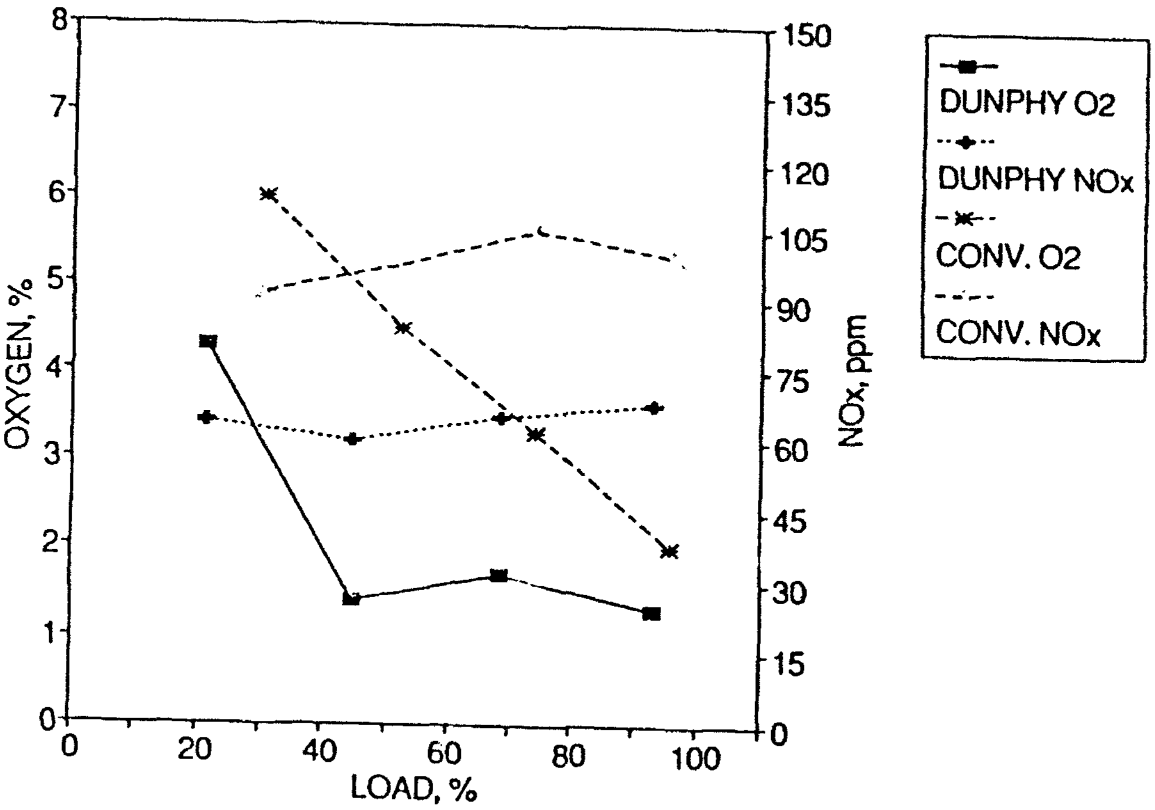


Figure 16. Comparison of O_2 and NO_x Levels for Gas Firing.

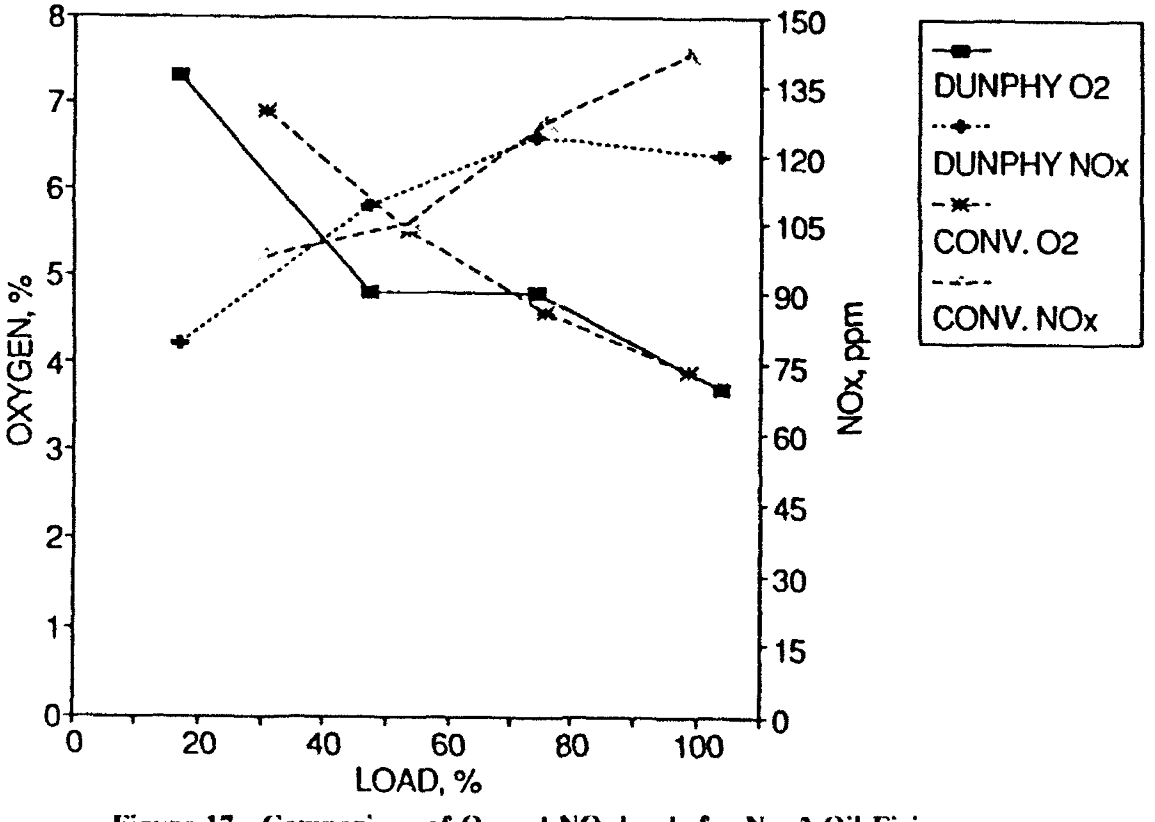


Figure 17. Comparison of O_2 and NO_x levels for No. 2 Oil Firing.

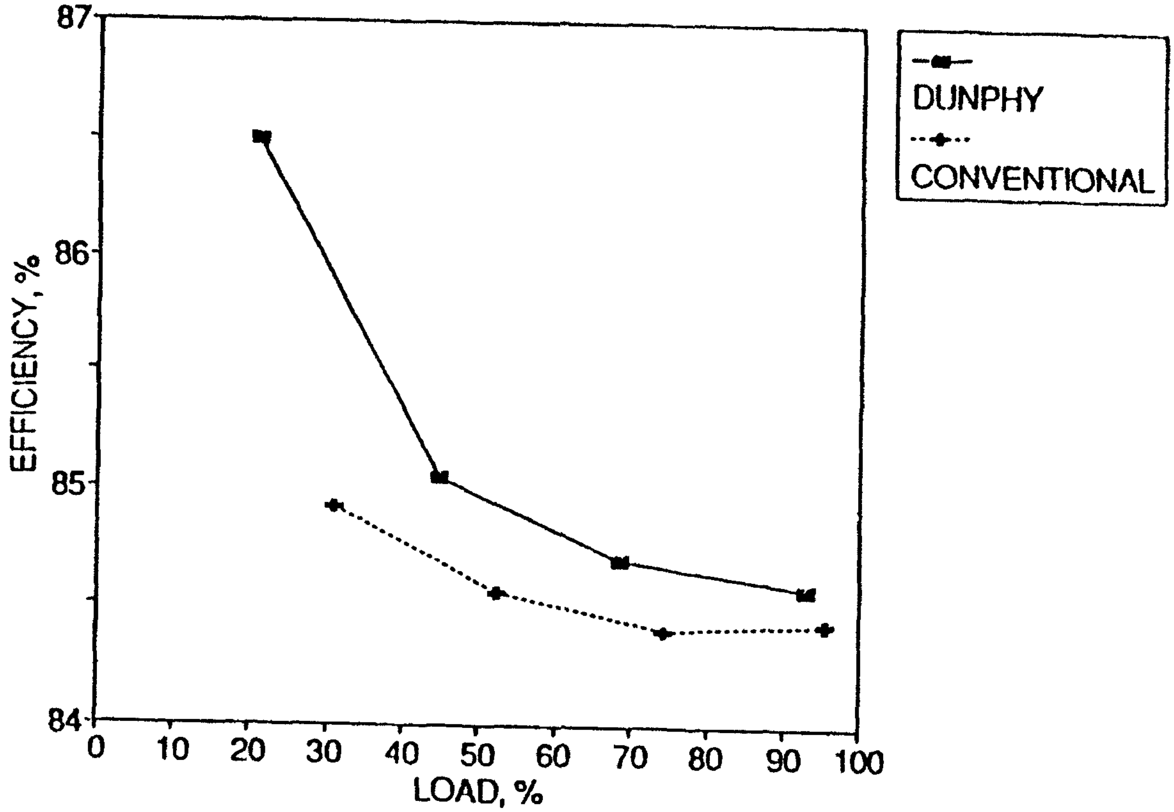


Figure 18. Comparison of Combustion Efficiency for Gas Firing.

Discussion of Results

Of the two burners installed for demonstration, no specific conclusions can be made for the Hague Transjet®. In the market survey, Hague indicated that their burner was a standard production item. However, Hague's continuing redesign and modification of the unit over the past 18 months to achieve basic operation and to fulfill performance claims shows this burner to still be in the research and development stage.

The Dunphy TD burner has been operated for a total of half of the 2-year test since it was installed. During this time, three of its components failed. However, because this burner was designed for accessibility, repair of these components was easy and was done by post personnel. The Dunphy maintained its performance level and did not require retuning. The baseline burner which was operated the other half of the 2-year period, experienced no failures, but did require one retuning of high fire gas flow.

Comparison of Dunphy and baseline performance and emission data shows that both burners had acceptable CO levels and similar stack temperatures. The Dunphy, however, had very low O_2 levels that the baseline burner could not achieve—at least while maintaining safe firing practices. These O_2 levels fulfilled Dunphy's claims and resulted in a 1 percent average efficiency advantage (85.5 - 84.5) over the baseline. At no point did Dunphy fulfill expectations for NO_x emissions, but it did demonstrate an average 35 percent reduction of baseline NO_x for gas firing.

With typical firing at an average annual rate of one third capacity on natural gas, Dunphy's efficiency gain will save 364 MBtu per year. This result can be interpreted in terms of recovery of investment. Its capital cost was $5000 more than a conventional replacement burner, but installation and maintenance costs are estimated to be equal. At a 7 percent discount factor and a starting gas cost of $2.69/MBtu, the additional cost of this burner can be recovered in slightly over 5 years.

Replacing conventional burners with dual fuel (natural gas and light oil) high-efficiency retrofit burners reduces the environmental impact of industrial size boiler operations. Because of the highly efficient use of fuel, these burners produce lower levels of carbon monoxide, combustible hydrocarbon and nitrogen oxide emissions.

7 CONCLUSIONS AND RECOMMENDATION

Conventional dual-fuel oil and gas burners on package boilers do not thoroughly mix fuel and air, or effectively atomize oil for complete combustion; nor are conventional burners generally designed to reduce NO_x emissions levels. High-efficiency, low-NO_x burners completely mix fuel and air, internally recirculate part of the combustion gases, and monitor the fuel/air ratio for more complete combustion, thus reducing NO_x emissions. A market survey showed that advanced dual fuel burners are available for retrofit to firetube boilers over the range of 4 to 30 x 10^6 Btu/h that offer significant improvement in terms of increased efficiency and decreased pollutant emissions by comparison with conventional burner systems. Although not developed specifically for firetube boilers (which perhaps are a more demanding application because of their potential for flame impingement), most advanced burners appear to be retrofitable to conventional boilers without major modifications.

Manufacturers' information showed that high-efficiency, low NO_x burners offer superior performance in terms of excess air requirement and pollutant emissions. The low excess air capability of these burners across the turndown range would allow significant improvements in boiler efficiency. Furthermore, retrofit of these burners would help reduce total pollutant emissions, and could reduce NO_x emissions by more than half the amount conventional burners generate. First stages of this demonstration identified several advanced burners and selected two, the Hague Transjet® and the Dunphy TD burners, for field testing.

This demonstration set up and performed a side-by-side comparison of conventional boilers with and without the high-efficiency burners. The boiler equipped with the Hague Transjet® boiler underwent significant redesign and modification during the 18 months of testing, and has not yet given conclusive results. The boiler fitted with the Dunphy TD burner showed acceptable CO levels and stack temperatures, and a 35 percent reduction in NO_x emissions. The Dunphy TD burner had O_2 levels that were consistent with safe practices and that resulted in a 1 percent average efficiency gain over the baseline. With typical firing, the savings gained by retrofit and use of this burner should recover the additional cost of the burner in slightly over 5 years.

The burners' performance appear to support the manufacturers' specifications and claims. However, some of the manufacturers' data are clearly estimates and require verification by further field testing.

METRIC CONVERSION TABLE

1 Btu	=	10.409 Liter-atmosphere
1 sq ft	=	0.093 m^2
1 cu ft	=	0.028 m^3
1 hp	=	10.68 kg-calories/min.
1 lb/sq in.	=	6.89 kPa

APPENDIX A: List of Burner Manufacturers Surveyed

A.A. Engelhardt, Inc.
Div. of Eclipse, Inc.
Sales Department
6117 N. Elston Ave.
Chicago, IL 60646
(312) 775-4800

Ace Engineering Co.
Sales Department
2850 N. Harrison
Chicago, IL 60612
(312) 722-7050

Acurex
Sales Department
P.O. Box 7555
Mountain View, CA 94039
(415) 964-3200

Aerogen Company, Ltd.
Sales Department
Newman Lane
Alton
Hampshire
United Kingdom
Phone: 0420 83744

Alzeta
Sales Department
2342 Calle Del Mundo
Santa Clara, CA 95054-1008
(408) 727-8282

Babcock & Wilcox Co.
Fossil Power Division
P.O. Box 351
20 S. Van Buren Ave.
Barberton, OH 44203
(216) 753-4511

Baker Perkins, Inc.
Sales Department
1000 Hess St.
Saginaw, MI 48601
(517) 752-4121

Barber Mfg. Co., Inc.
Sales Department
22903 Aurora Rd.
Bedford Heights, OH 44166
(216) 439-1680

Bard Manufacturing Co.
Sales Department
Evansport Rd.
Bryan, OH 43506
(419) 636-1194

BDP Company
Sales Department
7310 W. Morris St.
Indianapolis, IN 46231
(317) 243-0851

Beltran Associates
Sales Department
1133 E. 35th St.
Brooklyn, NY 11210
(718) 338-3311

Benraad BV
Sales Department
P.O. Box 5
7070 AA Ulft
The Netherlands
Phone: 08356-6641
Telex: 45029

Bertin and Cie
Sales Department
b.p.3 - 78370 Plaisir
Zone Industrielle
40220 Tarnos
France

Bloom Engineering Co., Inc.
Horning & Curry Rds.
Pittsburgh, PA 15236
(412) 892-2121

Blue Flame Division
UE Corporation
P.O. Box 266-T
Route 31
Ringoes, NJ 08551
(609) 466-1900

The British Combustion
Equipment Mfrs. Assn.
The Fernevy
Market Place
Midhurst
West Sussex, GU29 9DP
England
Phone: 073081 2782

Burdett Mfg. Co.
Sales Department
7460 W. 100th Pl.
Bridgeview, IL 60455
(312) 585-1141

Caloric
Gesellschaft fur Apparatebau m.b.H.
Sales Department
8032 Grafelfing bei Munchen
LohenstraBe 12
West Germany
Phone: 089/8542005
Telex: 5-29445

Cleaver Brooks
Div. of Aqua-Chem, Inc.
Sales Department
P.O. Box 421
Milwaukee, WI 53201
(414) 962-0100

Clyde Fuel Systems, Ltd.
Sales Department
Queen Elizabeth Ave.
Hillington
Glasgow, G52 4TE
United Kingdom
Phone: 041 882 3291

C.M. Kemp Mfg. Co.
Sales Department
705 Baltimore - Annapolis Blvd.
Glen Burnie, MD 21061
(301) 760-5100

Coen Company, Inc.
1510 Rollins Road
Burlingame, CA 94010
(415) 697-0440

Combustion Engineering, Inc.
Sales Department
1000 Prospect Hill Rd.
Windsor, CT 06095
(203) 688-1911

Coppus Engineering Corp.
Sales Department
P.O. Box 457
344 Park Ave.
Worcester, MA 01610
(617) 756-8393

Dr. Schmitz + Apelt
Industrieofenbau GmbH
Postfach 220347 D-5600 Wuppertal 22
ClausewitzstraBe 82-84
Wuppertal-Langerfeld
Federal Republic of Germany
Phone: 0202 6098-1
Telex: 8591802

DRU
Sales Department
Huttenweg 24
7071 BV Ulft
The Netherlands
Phone: 08356-4951
Telex: 45096

Dunham Busch, Inc.
Sales Department
101 Burgess Rd.
Harrisonburg, VA 22801
(703) 434-0711

Dunphy Oil & Gas Burners, Ltd.
Queensway
Rochdale, OL11 2SL
Lancashire
England
Phone: Rochdale 0706, 49217
Telex: 635071

Eclipse Combustion
Div. of Eclipse, Inc.
Sales Department
11005 Buchanan St.
Rockford, IL 61101
(815) 968-3751

Eisenwerk Theodor Loos GmbH
Export Department
D-8820 Gunsenhausen
Federal Republic of Germany
Phone: 09831/640
Cable: EISENWERK GUNZENHAUSEN
Telex: 61243

The Engineer Co.
Foot of Teeple Place
P.O. Box 39
South Plainfield, NJ 07080
(201) 755-2500

Flameco BV
Sales Department
P.O. Box 37
2800 AA Gouda
The Netherlands
Phone: 01820-15988
Telex: 20262

Forney Engineering Co.
Sales Department
P.O. Box 189
Addison, TX 75001
(214) 233-1871

Foster Wheeler
Sales Department
110 S. Orange Ave.
Livingston, NJ 07039
(201) 533-1100

Fuel Efficiency Inc.
Sales Department
P.O. Box 253
Clyde, NY 14433
(315) 923-2511

Furigas
Sales Department
P.O. Box 123
9400 AC Assen
The Netherlands
Phone: 05920-42441
Telex: 53945

General Combustion Co.
Sales Department
2140 W. Washington St.
Orlando, FL 32805
(305) 843-9890

Gordon-Piatt Energy Group, Inc.
P.O. Box 650
Winfield, Kansas 67156-0650
(316) 221-4770

Hague International
3 Adams St.
South Portland, ME 04106
(207) 799-7346

Hamworthy Engrg., Ltd.
Combustion Division
Fleets Corner
Poole
Dorset BH17 7LA
England
Phone: 0202-675123

Hauck Mfg. Co.
P.O. Box 499
Orland Park, IL 60462
(312) 460-2199

Hirt Co: ibustion Engineers
931 S. Maple Ave.
Montebello, CA 90640
(213) 728-9164

Hitachi Zosen
Maizuru Works
Sales Department
1180, Amarube-Shimo
Maizuru, Kyoto Pref, 625 Japan
Phone: 0773-63-1000
Telex: 5734-441

Hovin BV
Sales Department
Heulweg 29
2641 KP Pijnacker
The Netherlands
Phone: 01736-5797

H. Saacke Eurotherms, Ltd.
Sales Department
Fitzherbert Rd.
Farlington
Portsmouth, Hants., PO6 1RX
United Kingdom
Phone: 07018 83111

Iron-Fireman
Sales Department
101 Burgess Rd.
Harrisonburg, VA 22801
(703) 434-0711

Ishikawajima-Harima Heavy Ind.
Sales Department
New Otemachi Building
2-1, Otemachi 2-Chome
Chiyoda-Ku
Tokyo, 100 Japan

JHW of America, Inc.
Sales Department
135 Cumberland Rd.
Pittsburgh, PA 15237

Johnston Manufacturing Co.
Sales Department
2825 E. Hennepin Ave.
Minneapolis, MN 55413
(612) 331-7939

John Zink Co.
P.O. Box 702220
Tulsa, OK 74170
(918) 747-1371

Kawasaki Heavy Industries
Nissei Kawasaki Building
16-1, Nakamachi-Dori 2-Chome
Ikuta-Ku
Kobe, 650-91 Japan

Keeler-Dorr Oliver Co.
Sales Department
238 West St.
Williamsport, PA 17701
(717) 326-3361

Kobe Steel, Ltd.
Sales Department
3-18, Wakinohama-Cho 1-Chome
Fukiai-Ku
Kobe, 651 Japan
Phone: (078) 251-1551
Cable: KOBESTEEL KOBE
Telex: 5622-177 (KOBESTEEL KOB)

Kromschroder, AG
Sales Department
Postfach 2809
D4500 Osnabruck
West Germany

Laidlaw Drew & Co., Ltd.
Sales Department
Sighthill Industrial Estate
Edinburgh, EH11 4HG
United Kingdom
Phone: 031 443 4422

Leahy Manufacturing Co.
Sales Department
East 8th & Alameda
Los Angeles, CA 90021
(213) 623-1506

Max Weishaupt GmbH
Sales Department
D-7959 Schwendi 1
Federal Republic of Germany
Phone: 07353-830
Telex: 07-18-32

Maxon Corp.
Sales Department
201 E. 18th St.
P.O. Box 2068
Muncie, IN 47302
(317) 284-3304

Mid-Continental Metal Products
Sales Department
2717 North Greenview
Chicago, IL 60616
(312) 549-3900

Midland-Ross Corp.
Sales Department
900 N. Westwood
P.O. Box 985
Toledo, OH 43696
(419) 536-4611

Mitsubishi Heavy Ind., Ltd.
Sales Department
5-1, Marunouchi 2-Chome
Chiyoda-Ku
Tokyo, 100 Japan

NAO, Inc.
1284 E. Sedgley Ave.
Philadelphia, PA 19134
(215) 743-5300

Nebraska Boiler Co.
Sales Department
70th & Cornhusker Hwy.
Lincoln, NE 68501
(402) 464-7441

Nippon Furnace Kogyo Kaisha Ltd.
Sales Department
1-53, Shitte 2-Chome
Tsurumi-Ku
Yokohama, Kamagawa-Pres
230 Japan
Phone: 045-581-1281
Cable: FURNACE YOKOHAMA
Telex: 3822-340

North American Mfg. Co.
Sales Department
4455 E. 71st St.
Cleveland, OH 44105
(216) 271-6000

Nu-Way Eclipse, Ltd.
Sales Department
P.O. Box 14
Droitwich
Worcestershire
United Kingdom
Phone: 09057 4242

Nu-Way Heating Plants, Ltd.
Sales Department
P.O. Box 1
Vines Lane
Droitwich
Worcestershire
United Kingdom
Phone: 09057 2331

Oertli
c/o Tobler Bros.
Sales Department
6 E. 39th St.
New York, NY 10016

Osaka Gas Co., Ltd.
Sales Department
1 Hirano-Machi 5-Chome
Higashi-Ku
Osaka, 541 Japan

Peabody Engineering
Sales Department
835 Hope St.
Stamford, CT 06907
(203) 327-7000

Perfection Constructors Co.
Sales Department
P.O. Box 3544
Springfield, MA 01101
(413) 733-2895

Pillard Inc.
P.O. Box 24401
Louisville, KY 40224
(502) 423-7878

Process Combustion Corp.
Sales Department
1675 Washington Rd.
Pittsburgh, PA 15228
(412) 561-6200

Puripher
Sales Department
P.O. Box 64
2682 ZH De Lier
The Netherlands
Phone: 01745-4644
Telex: 31653

Pyronics, Inc.
Sales Department
17700 Miles Ave.
Cleveland, OH 44128
(216) 662-8800

Radiant Superjet, Ltd.
Sales Department
Clapgate Lane
Woodgate
Birmingham, B32 3BP
United Kingdom
Phone: 021 422 7221

Ransom Gas Industries, Inc.
Sales Department
2052 Farallon Dr.
San Leandro, CA 94577
(415) 352-3751

Ray Burner Co.
Sales Department
1301 San Jose Ave.
San Francisco, CA 94112
(415) 333-5800

Riello O.F.R. Ossicine
Frateooi Riello
Sales Department
Via Degli Alpini 1
37045 Legnago (VR)
Italy

Riley Stoker
Sales Department
3401 Richmond Rd.
Cleveland, OH 44122
(216) 464-8013

Riley Stoker
Sales Department
P.O. Box 547
Worcester, MA 01613
(617) 852-7100

Roberts-Gordon Appl. Corp.
Sales Department
44 Central Ave.
Buffalo, NY 14206
(716) 892-8400

Selas Corp. of America
Sales Department
Dresher, PA 12025
(215) 646-6600

Smit Ovens BV
P.O. Box 68
6500 AB Nihmegen
The Netherlands
Phone: (080) 523111

S.P. Kinney Engrs., Inc.
Sales Department
201 Second Ave.
Carnegie, PA 15106
(412) 276-4600

The Stacey Mfg. Co.
Sales Department
259 Township Ave.
Cincinnati, OH 45216
(513) 242-5772

Steinmuller GmbH
Sales Department
Gummersbach
Germany

S.T. Johnson Co.
Sales Department
925 Stanford Ave.
Oakland, CA 94608
(415) 652-6000

Stordy
Sales Department
Schouwstraat 26A
1435 KN Rijssenhout
The Netherlands
Phone: 02977-23411/23511
Telex: 18389

Stordy Combustions Engrg., Ltd.
Sales Department
Heath Mill Rd.
Wombourne
Wolverhampton, WV5 8BD
United Kingdom
Phone: 0902 897654

Sunbeam Equipment Corp.
Sales Department
200 Mercer St.
Meadville, PA 16335
(814) 724-1400

Superior Combustion Ind.
Sales Department
P.O. Box 156
801 Broad St.
Emmaus, PA 18049
(215) 965-9051

Syncro-Flame Inc.
Sales Department
4447 N. Oakland Ave.
Milwaukee, WI 53211
(414) 332-4100

Tate Jones
Sales Department
4057 Windgap Ave.
Pittsburgh, PA 15204
(412) 771-4200

T.C. Williams Burners Holme
Mfg. Co., Ltd.
Sales Department
Bradshaw Works
Bradshaw Rd.
Honley
Huddersfield, HD7 2DT
United Kingdom
Phone: 0484 662185

Thermal Systems Engrg., Inc.
Sales Department
185 New Boston St.
Woburn, MA 01801
(617) 933-7880

Tokyo Gas Co., Ltd
Sales Department
2-16, Yaesu 1-Chome
Chuo-Ku
Tokyo, 103 Japan

Trane Thermal Co.
Sales Department
250 Brook Rd.
Conshohocken, PA 19428
(215) 828-5400

TRW
Sales Department
One Space Park
Redondo Beach, CA 90278
(213) 535-4321

Voorheis Industries, Inc.
P.O. Box 1442
Fairfield, NJ 07006
(201) 227-2446

Walter H. Edwards Engrg. Corp.
Sales Department
Jamieson Lane
Indianapolis, IN 46268
(317) 251-2439

Webster Engrg. Div.
Sales Department
Box 748
Winfield, KS 67156
(316) 221-7464

Whites Burners
Sales Department
Industry Road
P.O. Box 2
Newcastle Upon Tyne, NE6 5TP
United Kingdom
Phone: 0632 658821/2

Wingaersheek, Inc.
Sales Department
2 Dearborn Rd.
Peabody, MA 01960
(617) 535-5300

W.N. Best Combustion Equip. Co.
Sales Department
11-3 South St.
Danbury, CT 06810
(203) 743-6741

APPENDIX B: Letter of Inquiry

August 4, 1987

Re:High-Efficiency/Low-NO_x Dual-Fuel Burners for Firetube Boilers

Gentlemen:

The Institute of Gas Technology (IGT) has been contracted by the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory (USA CERL) to select and recommend high-efficiency/low-NO_x burners for field tests on their firetube boilers.

The U.S. Army operates over a thousand firetube boilers in the 100 to 800 hp (4 to 32 million Btu/h) range burning light oil and natural gas. Retrofit of these boilers with the new generation of burners that are highly efficient across the turndown range and produce little pollutant emissions shows promise of being cost effective. Our current program consists of surveying the state-of-the-art in burner technology, followed by selection and acquisition of at least three burners for retrofit field testing.

Enclosed with this letter are the target specifications for the type of burners we are seeking and the questionnaire that we request you fill out. We expect that several burner sizes will be necessary to cover the entire range.

As mentioned above, these are "target specifications." Realizing the unique working conditions of this type of burner (small, water-cooled combustion chamber; large turndown ratio, etc.), these specifications may be difficult to achieve, so we will evaluate each burner or burner design in comparison with the others available.

We recognize your company's considerable experience in the combustion field, and we would greatly appreciate knowing if you have a burner suitable for this application and how well it meets the desired specifications. If appropriate, please send us all the available information regarding the existing burners or the burners under final development suitable for the application that we have described. Any operational information or recommendation regarding your experience with burners of this type would be helpful. Please carefully mark any information that you would like to remain confidential.

Also, include in your response information about burner availability, and its delivery and price schedules. We anticipate testing 8 million Btu/h burners on 200 hp boilers in an upcoming field test program.

A prompt response to this request will be appreciated. If you have any questions, please do not hesitate to contact Mr. Mark Khinkis at (312) 890-6445 or me at (312) 890-6443.

Sincerely,

Hamid Abbasi
Project Engineer
INSTITUTE OF GAS TECHNOLOGY
4201 W. 36th St.
Chicago, IL 60632

APPENDIX C:

Burner Manufacturers' Questionnaire Responses

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: Bloom Engineering Company, Inc.

Burner Model: Bloom #1060 Series

Burner Status: (Existing) Under Development (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

Weighted Points			
50	1.	Range of nominal burner size (Btu/h):	4×10^6 to 50×10^6 BTU/HR.
0	2.	Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	114,000 (4 & 8 MM BTU/HR) 71,000 (32 MM BTU/HR)
0	3.	Minimum required water-cooled combustion chamber diameter (inch)	
		at 4×10^6 Btu/h:	2'-6"
		at 8×10^6 Btu/h:	3'-0"
		at 32×10^6 Btu/h:	5'-0"
20	4.	Combustion chamber length-to-diameter ratio	
		at 4×10^6 Btu/h:	3
		at 8×10^6 Btu/h:	3.6
		at 32×10^6 Btu/h:	4.9

14 5. NO_x, CO, and UHC emissions with ambient combustion air for

	NO_x (ppm)	CO (ppm)	UHC (ppm)
a. Natural gas @2%O_2			
at nominal capacity:	60	*	*
at ___:1 turndown:	*	*	*
b. No. 2 oil @2%O_2 without fuel bound N_2			
at nominal capacity:	less than 60	*	*
at ___:1 turndown:	*	*	*

*Not Available

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS			
50	6.	Soot emissions for No 2 oil (Bacharach No.):	Less than 2
80	7.	Burner noise level (dba at 3 feet):	85 dba
219	8.	Excess air requirements	
		a. For natural gas firing	
		at nominal capacity (%):	0 to 10%
		at 5:1 turndown (%):	10 to 20%
		b. For No. 2 oil firing	
		at nominal capacity (5%):	10%
		at 5:1 turndown (%):	20%
20	9.	Required pressures	
		a. Air (in. wc):	28" WC
		b. Natural gas (in. wc):	2" WC
		c. No. 2 oil (lb/in.^{2}):	15 PSIG (4 & 8MM BTU/HR) 45 PSIG (32MM BTU/HR)
100	10.	Turndown ratio (burner output)	
		a. Natural gas:	9:1
		b. No. 2 oil:	7:1
	11.	Oil atomizing fluid	
		Type:	Steam or Air
		Flow (lb/lb oil):	0.2 LB/LB oil
		Pressure (psig):	15 PSIG (4 & 8 MM BTU/HR) 45 PSIG (32 MM BTU/HR)

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: Blue Flame Division, UE Corporation

Burner Model: ISOMAX®

Burner Status: Existing Under Development (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS		
50	1. Range of nominal burner size (Btu/h):	$4-15 \cdot 10^6$ (Std.); $>15 \times 10^6$ (special)
50	2. Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	200,000
30	3. Minimum required water-cooled combustion chamber diameter (inch)	
	at 4×10^6 Btu/h:	12"
	at 8×10^6 Btu/h:	16"
	at 32×10^6 Btu/h:	24" approx. est.
20	4. Combustion chamber length-to-diameter ratio	
	at 4×10^6 Btu/h:	3
	at 8×10^6 Btu/h:	3
	at 32×10^6 Btu/h:	(nd)

99 5. NO_x, CO, and UHC emissions with ambient combustion air for

	NO_x (ppm)	CO (ppm)	UHC (ppm)
a. Natural gas			
at nominal capacity:	49	20	-0-
at 2 :1 turndown:	48	15	-0-
b. No. 2 oil			
at nominal capacity:	54	25	-0-
at 2 :1 turndown:	55	20	-0-

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS			
75	6.	Soot emissions for No 2 oil (Bacharach No.):	-0-
80	7.	Burner noise level (dba at 3 feet):	85
300	8.	Excess air requirements	
		a. For natural gas firing	
		at nominal capacity (%):	-0-
		at 5:1 turndown (%):	-0-
		b. For No. 2 oil firing	
		at nominal capacity (5%):	-0-
		at 5:1 turndown (%):	-0-
8	9.	Required pressures	
		a. Air (in. wc):	40
		b. Natural gas (in. wc):	28
		c. No. 2 oil (lb/in.^{2}):	40
75	10.	Turndown ratio (burner output)	
		a. Natural gas:	5:1
		b. No. 2 oil:	4:1
	11.	Oil atomizing fluid	
		Type:	none
		Flow (lb/lb oil):	--
		Pressure (psig):	--

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: Coen Company

Burner Model: "DAF" Low Nox Burner

Burner Status: Existing **Under Development** (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS			
50	1.	Range of nominal burner size (Btu/h):	$4-35 \times 10^6$ Btu/Hr
50	2.	Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	150,000 — 350,000 Btu/hr/[illegible]
30	3.	Minimum required water-cooled combustion chamber diameter (inch)	
		at 4×10^6 Btu/h:	1'8"
		at 8×10^6 Btu/h:	2'6"
		at 32×10^6 Btu/h:	3'6"
20	4.	Combustion chamber length-to-diameter ratio	
		at 4×10^6 Btu/h:	6:1
		at 8×10^6 Btu/h:	5:1
		at 32×10^6 Btu/h:	5:1

84 5. NO_x, CO, and UHC emissions with ambient combustion air for

	NO_x (ppm)	CO (ppm)	UHC (ppm)
a. Natural gas			
at nominal capacity:	40	50	5
at 5:1 turndown:	40	50	5
b. No. 2 oil			
at nominal capacity:	* 40	50	5
at 5:1 turndown:	* 40	50	5

* Thermal NOx only -- Doesn't include Fuel NOx contribution due to bound N_2

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SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS			
50	6.	Soot emissions for No 2 oil (Bacharach No.):	2 OR LESS, (DEPENDING ON FUEL ANALYSIS).
80	7.	Burner noise level (dba at 3 feet):	UNDER 85 DBA
135	8.	Excess air requirements	
		a. For natural gas firing	
		at nominal capacity (%):	5-10%.
		at 5:1 turndown (%):	15-20%.
		b. For No. 2 oil firing	
		at nominal capacity (5%):	10-15%
		at 5:1 turndown (%):	25-30%
40	9.	Required pressures	
		a. Air (in. wc):	3" TO 6½" W.C.
		b. Natural gas (in. ~~wc~~):	2-7 PSIG
		c. No. 2 oil ($lb/in.^2$):	50-100 PSIG
100	10.	Turndown ratio (burner output)	
		a. Natural gas:	10 TO 1
		b. No. 2 oil:	8 TO 1
	11.	Oil atomizing fluid	
		Type:	AIR
		Flow (lb/lb oil):	≈ 8.8 SCFM/# OIL/MIN.
		Pressure (psig):	5-10 PSIG

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRFTUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: Dunphy Oil & Gas Burners Ltd

Burner Model: TD Series

Burner Status: Existing (underlined) Under Development (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS	Item	Response
50	1. Range of nominal burner size (Btu/h):	
50	2. Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	175,000 Btu/cu.ft/hr
30	3. Minimum required water-cooled combustion chamber diameter (inch)	
	at 4 X 10^6 Btu/h:	See attached appendix
	at 8 X 10^6 Btu/h:	
	at 32 X 10^6 Btu/h:	

WEIGHTED POINTS	4. Combustion chamber length-to-diameter ratio	MAXIMUM	MINIMUM
20	at 4 X 10^6 Btu/h:	5 - 1	1.8 - 1
	at 8 X 10^6 Btu/h:	5.2 - 1	1.6 - 1
	at 32 X 10^6 Btu/h:	4.7 - 1	1.7 - 1

WEIGHTED POINTS	5. NO_x, CO, and UHC emissions with ambient combustion air for	NO_x (ppm)	CO (ppm)	UHC (ppm)
100	a. Natural gas			
	at nominal capacity:	38	15	6
	at 4:1 turndown:	28	27	8
	b. No. 2 oil			
	at nominal capacity:	41	36	20
	at 4:1 turndown:	36	38	31

QUESTIONNAIRE, Cont.

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS			
50	6.	Soot emissions for No 2 oil (Bacharach No.):	1 - 2
			TD 2/3/4 TD 5
80	7.	Burner noise level (dba at 3 feet):	78/80 - 83
300	8.	Excess air requirements	
		a. For natural gas firing	
		at nominal capacity (%):	5 %
		at 5:1 turndown (%):	7 %
		b. For No. 2 oil firing	
		at nominal capacity (5%):	5 %
		at 5:1 turndown (%):	9 %
40	9.	Required pressures	
		a. Air (in. wc):	4" - 10" w.g.
		b. Natural gas (in. wc):	30" w.g.
		c. No. 2 oil ($lb/in.^2$):	Flooded Suction
100	10.	Turndown ratio (burner output)	Pressure Jet / Air
		a. Natural gas:	4 - 1 / 5 - 1
		b. No. 2 oil:	4 - 1 / 5 - 1
	11.	Oil atomizing fluid	
		Type:	Pressure Jet or Air
		Flow (lb/lb oil):	Dependent on Boiler efficiency
		Pressure (psig):	400 psi

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: THE ENGINEER COMPANY

Burner Model: LX VENTURI - WITH FLUE GAS RECIRCULATION

Burner Status: Existing Under Development (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS					
50	1. Range of nominal burner size (Btu/h):	5 TO 150 MILLION			
50	2. Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	75×10^3 BTU/FT^3-H TYPICAL			
30	3. Minimum required water-cooled combustion chamber diameter (inch)				
	at 4×10^6 Btu/h:	22			
	at 8×10^6 Btu/h:	32			
	at 32×10^6 Btu/h:	45			
20	4. Combustion chamber length-to-diameter ratio				
	at 4×10^6 Btu/h:	3.4 OR GREATER			
	at 8×10^6 Btu/h:	3.4 OR GREATER			
	at 32×10^6 Btu/h:	4.0 OR GREATER			
100	5. NO_x, CO, and UHC emissions with ambient combustion air for		NO_x (ppm)	CO (ppm)	UHC (ppm)
	a. Natural gas				
	at nominal capacity:		40	30	30
	at 10 :1 turndown:		40	40	40
	b. No. 2 oil				
	at nominal capacity:		50	30	40
	at 8 :1 turndown:		50	20	40

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS			
50	6.	Soot emissions for No 2 oil (Bacharach No.):	TWO OR LESS
80	7.	Burner noise level (dba at 3 feet):	LESS THAN 85
263	8.	Excess air requirements	
		a. For natural gas firing	
		at nominal capacity (%):	5%
		at 5:1 turndown (%):	15%
		b. For No. 2 oil firing	
		at nominal capacity (5%):	5%
		at 5:1 turndown (%):	15%
40	9.	Required pressures	
		a. Air (in. wc):	6 IN. WC THRU BURNER
		b. Natural gas (in. wc):	100" WC
		c. No. 2 oil (lb/in.^{2}):	100 PSIG
100	10.	Turndown ratio (burner output)	
		a. Natural gas:	10 TO 1
		b. No. 2 oil:	8 TO 1
	11.	Oil atomizing fluid	
		Type:	STEAM OR AIR
		Flow (lb/lb oil):	.1 LB/LB OIL
		Pressure (psig):	110 PSIG

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: FORNEY ENG. Co.

Burner Model: —

Burner Status: Existing Under Development (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS			
0	1.	Range of nominal burner size (Btu/h):	20 - 250 MKB
0	2.	Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	VARIES
0	3.	Minimum required water-cooled combustion chamber diameter (inch)	
		at 4×10^6 Btu/h:	
		at 8×10^6 Btu/h:	
		at 32×10^6 Btu/h:	45"
0	4.	Combustion chamber length-to-diameter ratio	
		at 4×10^6 Btu/h:	
		at 8×10^6 Btu/h:	
		at 32×10^6 Btu/h:	

0 5. NO_x, CO, and UHC emissions with ambient combustion air for

	NO_x (ppm)	CO (ppm)	UHC (ppm)
a. Natural gas			
at nominal capacity:	.2 lb/h		
at 5 :1 turndown:			
b. No. 2 oil			
at nominal capacity:	.2		
at 7 :1 turndown:			

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QUESTIONNAIRE, Cont.

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

EIGHTED POINTS			
50	6.	Soot emissions for No 2 oil (Bacharach No.):	< 20% opacity
80	7.	Burner noise level (dba at 3 feet):	85
150	8.	Excess air requirements	
		a. For natural gas firing	
		at nominal capacity (%):	2.5
		at 5:1 turndown (%):	
		b. For No. 2 oil firing	
		at nominal capacity (5%):	2.5
		at 5:1 turndown (%):	
40	9.	Required pressures	
		a. Air (in. wc):	6
		b. Natural gas (in. wc):	25 psig
		c. No. 2 oil ($lb/in.^2$):	150 psig
100	10.	Turndown ratio (burner output)	
		a. Natural gas:	5/1
		b. No. 2 oil:	7/1
	11.	Oil atomizing fluid	
		Type:	AIR
		Flow (lb/lb oil):	.13
		Pressure (psig):	170 psig or 90 psig

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: Gordon-Piatt Energy Group, Inc.

Burner Model: F10 Series

Burner Status: Existing (circled) Under Development (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS		
50	1. Range of nominal burner size (Btu/h):	4200 - 5250 MBH
50	2. Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	up to 250,000
30	3. Minimum required water-cooled combustion chamber diameter (inch)	
	at 4×10^6 Btu/h:	20
	at 8×10^6 Btu/h	
	at 32×10^6 Btu/h:	
20	4. Combustion chamber length-to-diameter ratio	
	at 4×10^6 Btu/h:	3.4:1
	at 8×10^6 Btu/h:	
	at 32×10^6 Btu/h:	

84 5. NO_x, CO, and UHC emissions with ambient combustion air for

	NO_x (ppm)	CO (ppm)	UHC (ppm)
a. Natural gas			
at nominal capacity:	50	20	40
at 3:1 turndown:	50	20	40
b. No. 2 oil			
at nominal capacity:	100	0	50
at 3:1 turndown:	100	0	50

QUESTIONNAIRE, Cont.

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS		
75	6. Soot emissions for No 2 oil (Bacharach No.):	No 1 or less
80	7. Burner noise level (dba at 3 feet):	80
99	8. Excess air requirements	
	a. For natural gas firing	
	at nominal capacity (%):	10%
	at 5:1 turndown (%):	25%
	b. For No. 2 oil firing	
	at nominal capacity (5%):	10%
	at 5:1 turndown (%):	30%
40	9. Required pressures	
	a. Air (in. wc):	6
	b. Natural gas (in. wc):	14
	c. No. 2 oil (lb/in.^{2}):	100
50	10. Turndown ratio (burner output)	
	a. Natural gas:	3:1
	b. No. 2 oil:	3:1
	11. Oil atomizing fluid	
	Type:	Air
	Flow (lb/lb oil):	.25
	Pressure (psig):	30

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: Hague International

Burner Model: Transjet

Burner Status: Existing (circled) Under Development (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS			
50	1.	Range of nominal burner size (Btu/h):	3×10^6 to 40×10^6
50	2.	Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	150×10^6
30	3.	Minimum required water-cooled combustion chamber diameter (inch)	
		at 4×10^6 Btu/h:	22"
		at 8×10^6 Btu/h:	28"
		at 32×10^6 Btu/h:	45"
20	4.	Combustion chamber length-to-diameter ratio	
		at 4×10^6 Btu/h:	6.0
		at 8×10^6 Btu/h:	5.4
		at 32×10^6 Btu/h:	5.2

100 5. NO_x, CO, and UHC emissions with ambient combustion air for

	NO_x (ppm)	CO (ppm)	UHC (ppm)
a. Natural gas			
at nominal capacity:	45	15	10
at 10 :1 turndown:	40	15	10
b. No. 2 oil			
at nominal capacity:	50	15	10
at 8 :1 turndown:	45	20	20

QUESTIONNAIRE, Cont.

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS			
50	6.	Soot emissions for No 2 oil (Bacharach No.):	2
80	7.	Burner noise level (dba at 3 feet):	85 dba at 3'
300	8.	Excess air requirements	
		a. For natural gas firing	
		at nominal capacity (%):	5.0%
		at 5:1 turndown (%):	10.0%
		b. For No. 2 oil firing	
		at nominal capacity (5%):	5.0%
		at 5:1 turndown (%):	10.0%
36	9.	Required pressures	
		a. Air (in. wc):	Combustion Air: 10
		b. Natural gas (in. wc):	50
		c. No. 2 oil ($lb/in.^2$):	100
100	10.	Turndown ratio (burner output)	
		a. Natural gas:	10.0
		b. No. 2 oil:	8.0
	11.	Oil atomizing fluid	
		Type:	Air
		Flow (lb/lb oil):	0.05
		Pressure (psig):	80

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: HAMWORTHY ENGINEERING LTD. COMBUSTION DIVISION

Burner Model: AW ROTARY CUP BURNERS

Burner Status: Existing Under Development (circle one)

EXISTING, BUT WE OPERATE A POLICY OF CONTINUOUS DEVELOPMENT

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS			
40	1.	Range of nominal burner size (Btu/h):	SEE BROCHURE ENCLOSED
50	2.	Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	HAVE SUPPLIED TO 250,000 BTU/FT^3/HR. HOWEVER, WITH CURRENT CLEAN AIR LEGISLATION MOST EUROPEAN BOILERMAKERS ~~NOW DESIGN TO APPROXIMATELY 1~~60,000 BTU/FT^3/HR.
15	3.	Minimum required water-cooled combustion chamber diameter (inch)	
		at 4×10^6 Btu/h:	STD MIN DIA 26 INS
		at 8×10^6 Btu/h:	26 INS
		at 32×10^6 Btu/h:	44 INS
			THIS TO SOME EXTENT IS DICTATED BY STD QUARL BRICK DIMENSIONS AND COULD BE RECONSIDERED
20	4.	Combustion chamber length-to-diameter ratio	
		at 4×10^6 Btu/h:	STD DESIGN APPROX 4:1
		at 8×10^6 Btu/h:	4:1
		at 32×10^6 Btu/h:	4:1

74 5. NO_x, CO, and UHC emissions with ambient combustion air for

	NO_x (ppm)	CO (ppm)	UHC (ppm)
a. Natural gas			
at nominal capacity:			
at ___:1 turndown:			
b. No. 2 oil	SEE TABLE NO 1		
at nominal capacity:			
at ___:1 turndown:			

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Q U E S T I O N N A I R E, Cont.

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS			
50	6.	Soot emissions for No 2 oil (Bacharach No.):	2
80	7.	Burner noise level (dba at 3 feet):	UNSILENCED 94 96 SILENCED 80 83 SMALL LARGE BURNERS
39	8.	Excess air requirements	SEE DATA SHEET 01:03:26 ENCLOSED.
		a. For natural gas firing	THIS SHOWS TYPICAL DESIGN RANGE
		at nominal capacity (%):	FOR EUROPEAN FIRETUBE BOILER DESIGN
		at 5:1 turndown (%):	AND DOES NOT NECESSARILY REPRESENT
			A BURNER LIMIT
		b. For No. 2 oil firing	
		at nominal capacity (5%):	
		at 5:1 turndown (%):	
40	9.	Required pressures	REGISTER DRAFT LOSS [RDL] NORMAL DESIGN RANGE 4-8 INS WG DEPENDING ON BOILER DESIGN ETC.
		a. Air (in. wc):	
		b. Natural gas (in. wc):	NORMAL DESIGN 10-15 INS WG
		c. No. 2 oil ($lb/in.^2$):	5-15 LBF/INS^2G
75	10.	Turndown ratio (burner output)	NORMAL DESIGN RANGE
		a. Natural gas:	SMALL BURNERS 4:1
		b. No. 2 oil:	LARGE BURNERS 5:1
	11.	Oil atomizing fluid	PRIMARY AIR, INTEGRAL SUPPLY WITH COMBUSTION AIR SYSTEM
		Type:	
		Flow (lb/lb oil):	APPROXIMATELY 7% OF TOTAL AIR
		Pressure (psig):	APPROXIMATELY 35 INS WG

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: Hauck Manufacturing Company

Burner Model: Nozzle Mix Combination Burner

Burner Status: Existing | Under Development (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS			
50	1.	Range of nominal burner size (Btu/h):	.5 to 40 MMBTUH
50	2.	Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	150,000 Btu/sq ft-h
15	3.	Minimum required water-cooled combustion chamber diameter (inch)	
		at 4 X 10^6 Btu/h:	14 inches
		at 8 X 10^6 Btu/h:	20 inches
		at 32 X 10^6 Btu/h:	48 inches
20	4.	Combustion chamber length-to-diameter ratio	
		at 4 X 10^6 Btu/h:	3.3
		at 8 X 10^6 Btu/h:	5.1
		at 32 X 10^6 Btu/h:	5.2

25 5. NO_x, CO, and UHC emissions with ambient combustion air for

	NO_x (ppm)	CO (ppm)	UHC (ppm)
a. Natural gas			
at nominal capacity: 12MM	0	31	
at ___:1 turndown:			
b. No. 2 oil			
at nominal capacity:	N/A		
at ___:1 turndown:			

QUESTIONNAIRE, Cont.

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS	Item	Response
0	6. Soot emissions for No 2 oil (Bacharach No.):	N/A
80	7. Burner noise level (dba at 3 feet):	Less than 85 dba
300	8. Excess air requirements	
	a. For natural gas firing	
	at nominal capacity (%):	0
	at 5:1 turndown (%):	0
	b. For No. 2 oil firing	
	at nominal capacity (5%):	5%
	at 5:1 turndown (%):	10%
20	9. Required pressures	
	a. Air (in. wc):	28 "WC
	b. Natural gas (in. wc):	10 "WC
	c. No. 2 oil ($lb/in.^2$):	35 psi
100	10. Turndown ratio (burner output)	
	a. Natural gas:	10:1
	b. No. 2 oil:	8:1
	11. Oil atomizing fluid	
	Type:	Combustion Air Blower
	Flow (lb/lb oil):	
	Pressure (psig):	One psi

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: HIRT COMBUSTION ENGINEERS

Burner Model: HIRT PRECISION / PRE-MIX BURNER

Burner Status: **Existing** Under Development (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS					
50	1. Range of nominal burner size (Btu/h):	4MM, 8MM, 32MM			
50	2. Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	N/A			
30	3. Minimum required water-cooled combustion chamber diameter (inch)				
	at 4×10^6 Btu/h:	17" ø			
	at 8×10^6 Btu/h:	22" ø			
	at 32×10^6 Btu/h:	36" ø			
20	4. Combustion chamber length-to-diameter ratio				
	at 4×10^6 Btu/h:	N/A			
	at 8×10^6 Btu/h:	N/A			
	at 32×10^6 Btu/h:	N/A			
84	5. NO_x, CO, and UHC emissions with ambient combustion air for				
			NO_x (ppm)	CO (ppm)	UHC (ppm)
	a. Natural gas				
	at nominal capacity:		50	50	50
	at 8 :1 turndown:		50	50	50
	b. No. 2 oil				
	at nominal capacity:		150	50	50
	at 5 :1 turndown:		150	50	50

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS			
50	6.	Soot emissions for No 2 oil (Bacharach No.):	LESS THAN RINGLEMAN #1
80	7.	Burner noise level (dba at 3 feet):	85 dba
300	8.	Excess air requirements	
		a. For natural gas firing	
		at nominal capacity (%):	0%
		at 5:1 turndown (%):	0%
		b. For No. 2 oil firing	
		at nominal capacity (5%):	~0% (APPROX.)
		at 5:1 turndown (%):	~0% (APPROX.)
20	9.	Required pressures	
		a. Air (in. wc):	27.7
		b. Natural gas (in. wc):	55.4
		c. No. 2 oil ($lb/in.^2$):	100 PSIG
100	10.	Turndown ratio (burner output)	
		a. Natural gas:	8:1
		b. No. 2 oil:	5:1
	11.	Oil atomizing fluid	
		Type:	STEAM
		Flow (lb/lb oil):	.3 lb/lb
		Pressure (psig).	100 PSIG

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: NAO, INC.

Burner Model: FD-VHESP

Burner Status: Existing   Under Development   (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS					
50	1. Range of nominal burner size (Btu/h):	4-32 MM			
0	2. Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	60,000			
30	3. Minimum required water-cooled combustion chamber diameter (inch)				
	at 4×10^6 Btu/h:	18"			
	at 8×10^6 Btu/h:	23"			
	at 32×10^6 Btu/h:	39"			
20	4. Combustion chamber length-to-diameter ratio				
	at 4×10^6 Btu/h:	2.1			
	at 8×10^6 Btu/h:	4.2			
	at 32×10^6 Btu/h:	10.0			
81	5. NO_x, CO, and UHC emissions with ambient combustion air for				
			NO_x (ppm)	CO (ppm)	UHC (ppm)
	a. Natural gas				
	at nominal capacity:		60	10	
	at ___:1 turndown:		60	10	
	b. No. 2 oil				
	at nominal capacity:		100	10	
	at ___:1 turndown:		100	10	

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS		
75	6. Soot emissions for No 2 oil (Bacharach No.):	approx. 0
0	7. Burner noise level (dba at 3 feet):	See Data Sheets Enclosed
0	8. Excess air requirements	
	a. For natural gas firing	
	at nominal capacity (%):	20
	at 5:1 turndown (%):	
	b. For No. 2 oil firing	
	at nominal capacity (5%):	15
	at 5:1 turndown (%):	
40	9. Required pressures	
	a. Air (in. wc):	1
	b. Natural gas (in. wc):	15
	c. No. 2 oil ($lb/in.^2$):	80
50	10. Turndown ratio (burner output)	
	a. Natural gas:	5:1
	b. No. 2 oil:	3:1
	11. Oil atomizing fluid	
	Type:	steam
	Flow (lb/lb oil):	.15
	Pressure (psig):	100

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: Pillard, Inc.

Burner Model: (Castor) Beaver

Burner Status: Existing Under Development (circle one)

Gaz Oil

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS		
50	1. Range of nominal burner size (Btu/h):	4×10^6 to 32×10^6 BTU/h
50	2. Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	150,000 to 220,000 BTU/ft^3-h
15	3. Minimum required water-cooled combustion chamber diameter (inch)	
	at 4×10^6 Btu/h:	22 inches
	at 8×10^6 Btu/h:	
	at 32×10^6 Btu/h:	50 inches
20	4. Combustion chamber length-to-diameter ratio	
	at 4×10^6 Btu/h:	3.4
	at 8×10^6 Btu/h:	
	at 32×10^6 Btu/h:	6

84 5. NO_x, CO, and UHC emissions with ambient combustion air for

	NO_x (ppm)	CO (ppm)	UHC (ppm)
a. Natural gas			
at nominal capacity:	50	50	-
at 5:1 turndown:	50	50	-
b. No. 2 oil (TARGET)			
at nominal capacity:	75	50	50
at 3:1 turndown:	75	50	50

QUESTIONNAIRE, Cont.

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS		
0	6. Soot emissions for No 2 oil (Bacharach No.):	3 to 4
80	7. Burner noise level (dba at 3 feet):	85
180	8. Excess air requirements	
	a. For natural gas firing	
	at nominal capacity (%):	8
	at 5:1 turndown (%):	20
	b. For No. 2 oil firing	
	at nominal capacity (5%):	12
	at ~~5:1~~ 3:1 turndown (%):	20
40	9. Required pressures	
	a. Air (in. wc):	6 inch wc
	b. Natural gas (in. wc):	120 to 600 inch wc
	c. No. 2 oil ($lb/in.^2$):	10.5 $lb/in.^2$
50	10. Turndown ratio (burner output)	
	a. Natural gas:	5:1
	b. No. 2 oil:	3:1
	11. Oil atomizing fluid	
	Type:	Mechanical
	Flow (lb/lb oil):	-
	Pressure (psig):	-

WEIGHTED POINTS - 427
(Average for 3 sizes)

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: Dr. SCHMITZ + APELT INDUSTRIEOFENBAU GMBH

Burner Model: S F O G 1700

Burner Status: Existing   Under Development   (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

Average for 3 sizes) WEIGHTED POINTS			
40	1.	Range of nominal burner size (Btu/h):	6 mill Btu/h ≙ 1.5 Gcal/h
43	2.	Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	168.000 Btu/ft³-h ≙ 1.49 Gcal/m³
0	3.	Minimum required water-cooled combustion chamber diameter (inch)	
		at 6 X 10^6 Btu/h:	800 mm = 31.5 "
		at 8 X 10^6 Btu/h:	
		at 32 X 10^6 Btu/h:	
20	4.	Combustion chamber length-to-diameter ratio	
		at 6 X 10^6 Btu/h:	(2000 mm) 2.5 : 1
		at 8 X 10^6 Btu/h:	
		at 32 X 10^6 Btu/h:	

28 5. NO_x, CO, and UHC emissions with ambient combustion air for

	NO_x (ppm)	CO (ppm)	UHC (ppm)
a. Natural gas			
at nominal capacity:			
at 4 :1 turndown:	<100	<100	<100
b. No. 2 oil			
at nominal capacity:			
at 4 :1 turndown:	<150	<100	<100

I N S T I T U T E   O F   G A S   T E C H N O L O G Y

QUESTIONNAIRE, Cont.

(Average for 3 sizes) WEIGHTED POINTS

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Weighted points	Item	Answer
50	6. Soot emissions for No 2 oil (Bacharach No.):	< 2
0	7. Burner noise level (dba at 3 feet):	depending on plant
14	8. Excess air requirements	
	a. For natural gas firing	
	at nominal capacity (%):	
	at 4:1 turndown (%):	abt. 10 - 15 %
	b. For No. 2 oil firing	
	at nominal capacity (5%):	
	at 4:1 turndown (%):	abt. 15 - 20 %
32	9. Required pressures	
	a. Air (in. wc):	350 mm WC
	b. Natural gas (in. wc):	350 mm WC
	c. No. 2 oil ($lb/in.^2$):	145 lb/sq in ≙10 bar
100	10. Turndown ratio (burner output)	
	a. Natural gas:	1 : 4
	b. No. 2 oil:	1 : 4
	11. Oil atomizing fluid	
	Type:	Mineral oil
	Flow (lb/lb oil):	10 % of max. oil throughput ≙ 33 ≙15 k
	Pressure (psig):	102 lb/sq in ≙7 bar

QUESTIONNAIRE

WEIGHTED POINTS - 788

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: SMIT OVENS B.V.

Burner Model: SMIT ULTRAMIZING ©

Burner Status: Existing   Under Development   (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS			
50	1.	Range of nominal burner size (Btu/h):	$3,2 \times 10^6$ to $32,2 \times 10^6$ Btu/h
50	2.	Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	220,000 Btu/ft^3-h
30	3.	Minimum required water-cooled combustion chamber diameter (inch)	
		at 4×10^6 Btu/h:	21 inch
		at 8×10^6 Btu/h:	26 inch
		at 32×10^6 Btu/h:	44 inch
20	4.	Combustion chamber length-to-diameter ratio	
		at 4×10^6 Btu/h:	3,4 : 1
		at 8×10^6 Btu/h:	3,8 : 1
		at 32×10^6 Btu/h:	4 : 1

67 5. NO_x, CO, and UHC emissions with ambient combustion air for

	NO_x (ppm)	CO (ppm)	UHC (ppm)
a. Natural gas			
at nominal capacity:	150	< 50	< 5
at 6 :1 turndown:	80	< 50	< 5
b. No. 2 oil depending on burner size			
at nominal capacity:	150	50	5
at 6 :1 turndown:	80	50	5

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS			
75	6.	Soot emissions for No 2 oil (Bacharach No.):	zero at 1% 02
80	7.	Burner noise level (dba at 3 feet):	Depending on boiler design, abt. 85
300	8.	Excess air requirements	
		a. For natural gas firing	
		at nominal capacity (%):	4%
		at 5:1 turndown (%):	4%
		b. For No. 2 oil firing	
		at nominal capacity (5%):	4%
		at 5:1 turndown (%):	4%
16	9.	Required pressures	
		a. Air (in. wc):	31 in w.c.
		b. Natural gas (in. wc):	40 in w.c.
		c. No. 2 oil ($lb/in.^2$):	290 lb/in^2
100	10.	Turndown ratio (burner output)	
		a. Natural gas:	6:1
		b. No. 2 oil:	6:1
	11.	Oil atomizing fluid	
		Type:	Not required
		Flow (lb/lb oil):	
		Pressure (psig):	

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: Voorheis Industries, Inc.

Burner Model: Bluff-Body™

Burner Status: Existing   Under Development   (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS			
50	1.	Range of nominal burner size (Btu/h):	4 to 32 million
50	2.	Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	All suitable
30	3.	Minimum required water-cooled combustion chamber diameter (inch)	
		at 4×10^6 Btu/h:	20
		at 8×10^6 Btu/h:	24
		at 32×10^6 Btu/h:	44
18	4.	Combustion chamber length-to-diameter ratio	
		at 4×10^6 Btu/h:	7
		at 8×10^6 Btu/h:	7
		at 32×10^6 Btu/h:	5

100   5. NO_x, CO, and UHC emissions with ambient combustion air for

	NO_x (ppm)	CO (ppm)	UHC (ppm)
a. Natural gas			
at nominal capacity:	10	10	10
at 5 :1 turndown:	40	5	5
b. No. 2 oil			
at nominal capacity:	20	10	10
at 5 :1 turndown:	50	10	10

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS	Item	Specification
50	6. Soot emissions for No 2 oil (Bacharach No.):	Less than 2
80	7. Burner noise level (dba at 3 feet):	Less than 80
300	8. Excess air requirements	
	a. For natural gas firing	
	at nominal capacity (%):	Less than 5%
	at 5:1 turndown (%):	Less than 10%
	b. For No. 2 oil firing	
	at nominal capacity (5%):	Less than 8%
	at 5:1 turndown (%):	Less than 12%
40	9. Required pressures	
	a. Air (in. wc):	4" W.C. drop across register at hi[illegible]
	b. Natural gas (in. wc):	8" W.C. " " " " "
	c. No. 2 oil ($lb/in.^2$):	Approx 100 PSI
100	10. Turndown ratio (burner output)	
	a. Natural gas:	Turndown is not limited
	b. No. 2 oil:	5:1 minimum
	11. Oil atomizing fluid	
	Type:	Air or steam
	Flow (lb/lb oil):	3.0 or 0.10 (high fire)
	Pressure (psig):	5 or 10 (not modulated)

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: Max Weishaupt GmbH

Burner Model: WKGL 3/0-A

Burner Status: Existing X Under Development (circle one)

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS			
50	1.	Range of nominal burner size (Btu/h):	7.85×10^6 to 40.96×10^6
		(kW)	2300 to 12000
44	2.	Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	
0	3.	Minimum required water-cooled combustion chamber diameter (inch)	
		at 4×10^6 Btu/h:	
		at 8×10^6 Btu/h:	
		at 32×10^6 Btu/h:	47 (1.2 m)
20	4.	Combustion chamber length-to-diameter ratio	
		at 4×10^6 Btu/h:	
		at 8×10^6 Btu/h:	
		at 32×10^6 Btu/h:	4.8

34 5. NO_x, CO, and UHC emissions with ambient combustion air for

	NO_x (~~ppm~~ mg/m³n)	CO (~~ppm~~ mg/m³n)	UHC (~~ppm~~ mg/m³n)
a. Natural gas			
at nominal capacity:	150 (80)	< 80	< 10
at ___:1 turndown:			
b. No. 2 oil			
at nominal capacity:	230 (160)	< 50	< 10
at ___:1 turndown:			

NOx calculated as NO_2 and at 3 % O_2; (   ) with flue gas feed back

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS			
75	6.	Soot emissions for No 2 oil (Bacharach No.):	< 1
80	7.	Burner noise level (dba at 3 feet):	approx. 85
135	8.	Excess air requirements	
		a. For natural gas firing	
		at nominal capacity (%):	5
		at 5:1 turndown (%):	25
		b. For No. 2 oil firing	
		at nominal capacity (5%):	10
		at 5:1 turndown (%):	40
24	9.	Required pressures	
		a. Air (in. wc):	20.9 (50 mbar)
		b. Natural gas (in. wc):	209 (500 mbar)
		c. No. 2 oil ($lb/in.^2$):	14.5 (1 bar)
25	10.	Turndown ratio (burner output)	
		a. Natural gas:	4.778×10^6 Btu/h (1400 kW)
		b. No. 2 oil:	7.851×10^6 Btu/h (2300 kW)
	11.	Oil atomizing fluid	
		Type:	-
		Flow (lb/lb oil):	
		Pressure (psig):	

QUESTIONNAIRE

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

Company Name: JOHN ZINK COMPANY

Burner Model: HPS-SF/SA (Staged fuel for gas and staged air for oil)

Burner Status: Existing * Under Development (circle one)
*Utilized for other applications

Note: Please fill in a separate sheet for each burner size within the target range, if the specifications are different.

Please indicate units if different from those listed.

WEIGHTED POINTS			
40	1.	Range of nominal burner size (Btu/h):	5M Btu/hr to 200M Btu/hr
50	2.	Combustion chamber specific heat density at nominal capacity (Btu/ft^3-h):	See below
30	3.	Minimum ~~required~~ allowable water-cooled combustion chamber diameter (inch)	Estimated Dimensions
		at 4 X 10^6 Btu/h:	Flame 20 in x 6ft
		at 8 X 10^6 Btu/h:	Flame 26 in x 9 ft
		at 32 X 10^6 Btu/h:	Flame 42 in x 16 ft
20	4.	Combustion chamber length-to-diameter ratio	
		at 4 X 10^6 Btu/h:	See above
		at 8 X 10^6 Btu/h:	
		at 32 X 10^6 Btu/h:	

84 5. NO_x, CO, and UHC emissions with ambient combustion air for

Corrected to 3% O_2

	NO_x (ppm)	CO (ppm)	UHC (ppm)
a. Natural gas			
at nominal capacity:	50	50	50
at 5 :1 turndown:	50	?	?
b. No. 2 oil			
at nominal capacity:	90	50	50
at 5 :1 turndown:	90	?	?

Q U E S T I O N N A I R E, Cont.

SPECIFICATIONS FOR HIGH-EFFICIENCY/LOW-NO_x DUAL-FUEL BURNER FOR FIRETUBE BOILERS RANGING FROM 100 hp UP TO 800 hp

WEIGHTED POINTS		
50	6. Soot emissions for No 2 oil (Bacharach No.):	two or less
80	7. Burner noise level (dba at 3 feet):	As required
270	8. Excess air requirements	
	a. For natural gas firing	
	at nominal capacity (%):	5%
	at 5:1 turndown (%):	10%
	b. For No. 2 oil firing	
	at nominal capacity (%):	10%
	at 5:1 turndown (%):	15%
36	9. Required pressures	
	a. Air (in. wc):	10 in.w.c.
	b. Natural gas (in. wc):	As required
	c. No. 2 oil (lb/in.^{2}):	150 psig *
100	10. Turndown ratio (burner output)	
	a. Natural gas:	5:1
	b. No. 2 oil:	5:1
	11. Oil atomizing fluid	
	Type:	Air or steam
	Flow (lb/lb oil):	0.3
	Pressure (psig):	150

*150 psig oil pressure should not be a problem for user.

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National Guard Bureau 20310
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